2021 INTERNATIONAL AIRCRAFT CABIN AIR CONFERENCE



CONFERENCE PROCEEDINGS

Presentations, Abstracts and Papers of the 2021 International Aircraft Cabin Air Conference

15-18 March 2021

Online, Zoom

GCAQE

Global Cabin Air Quality Executive

Tristan Lorain (Conference Director)
Dieter Scholz, Susan Michaelis (Editors)

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2021 International Aircraft Cabin Air Conference

15-18 March 2021, Online, Zoom

London: Global Cabin Air Quality Executive (GCAQE)

2021

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Abstract

The International Aircraft Cabin Air Conferences have developed into a series of conferences that were organized so far in 2017, 2019 and 2021. The conferences are mapping the business, regulatory and technical solutions to aircraft cabin air contamination. These proceedings contain the contributions to the conference in 2021. From the 39 contributions to the conference 33 are included in the proceedings. Most contributions are contained in the proceedings in form of a presentation. Some are contained in more than one format (adding an extended abstract or a paper). For this reason the proceedings contain 48 documents and links to 11 short documentary films, all together on 791 pages.

Introduction to the Proceedings

The International Aircraft Cabin Air Conferences have developed into a series of conferences that were so far **organized every two years**. The conferences are mapping the business, regulatory and technical solutions to aircraft cabin air contamination.

The conferences in 2017, 2019 and 2021 provided much information for those seeking to **understand the subject of contaminated air**, the flight safety implications, the latest scientific and medical evidence investigating the contaminated air debate and the solutions available to airlines and aircraft operators. The three conferences held so far have been the most in-depth conferences ever on the topic of aircraft cabin air contamination.

By way of expert global independent and industry speakers, the Aircraft Cabin Air Conferences seek to achieve the following key **objectives**:

- Provide a historical overview of the contaminated air issue and its causes.
- Map out the flight safety aspects of contaminated air through case studies, discussion and air accident investigation findings.
- Disseminate the latest medical and scientific theories and findings on the health aspects of exposure to contaminated air.
- Give guidance of the regulatory aspects of cabin air quality.
- Examine the latest development towards bleed air filtration, contaminated air warning sensor systems and other potential solutions.
- Provide an opportunity for networking and sharing good practice to facilitate better inter-agency working.

The **2021 International Aircraft Cabin Air Conference** was a four-day free modular online event via Zoom. Contributions were grouped into these **sessions**:

1. Introductions and the history of the issue
2. Understanding engine seals and exposure
3. Global perspectives
4. Operational aspects
5. Air Accident incidents and findings
6. Air monitoring and measuring
7. Introduction to organophosphates
8. The toxicology and neutoxicity of contaminated air
9. Occupational health and exposures
10. Safety analysis and biomarkers of exposure
11. The legal aspects of contaminated air exposures
12. Filtration solutions

Please refer to the
Conference Programme 2021 (https://doi.org/10.5281/zenodo.4627005)
for additional information not repeated here:

- List of conference speakers
- Schedule of the conference
- Sponsors and supporters

There were **39 contributions to the conference**. Unfortunately, six of them are not in the proceedings. Among the remaining 33:

- 4 were given as a *Speech*. These speeches got converted to a *Conference Paper*.
- One *Presentation* was provided for the proceedings only in the form of a short *Conference Paper* (not as a presentation).
- The remaining 28 contributions are included in the proceedings in the form of a *Presentation*.

To these 28 *Presentations*, 15 documents were added to provide an additional format and as such more information:

- To fife Presentations an *Extended Abstract* was added.
- To seven Presentations a *Conference Paper* was added.
- To one presentation a *Journal Paper* was added.
- To one presentation a *Conference Paper* was added and later also a *Journal Paper*.

All together this gives 33 plus 15, hence in total **48 documents** that are included in these *Proceedings of the 2021 International Aircraft Cabin Air Conference*. The proceedings are not consecutively numbered, but have a known total of **791 pages**. The documents are sorted

alphabetically by the main author's last name in the proceedings and in its *Table of Contents*. Every document is given in the Table of Contents with

- the title that links to the document in the proceedings,
- a Digital Object Identifier (DOI) that links to the document's individual online landing page. Journal papers use the DOI provided by the journal.
- If there is more than one format of the contribution the sequence is (as far as available):
  1. journal paper
  2. conference paper
  3. extended abstract
  4. presentation
- In addition the proceedings have a PDF table of contents (in form of a sidebar), which can also be used to navigate the bulky file.

When individual conference contributions are made available chances are much higher they are found by search engines. Most libraries however, require **traditional proceedings** for copyright reasons or because their capacity is limited and they can deal with only one single document for every conference in their catalog and archive.

An online **repository** (or "community") called "International Aircraft Cabin Air Conferences – Proceedings" (https://zenodo.org/communities/aircraftcabinair) exists, which contains all the **individual contributions to the conferences** each with its own **landing page** and a persistent Digital Object Identifier (**DOI**). The repository makes use of the Open Science Service "Zenodo" (https://zenodo.org) funded by the European Union and run by CERN (https://home.cern). CERN is a large international research organization, where (among many other achievements) the World Wide Web was invented.

There are several ways, how a conference contribution can be quoted. These are the possibilities:

Citation of the complete proceedings (ISO 690):
SCHOLZ, Dieter, MICHAELIS, Susan (Ed.), 2021. *2021 International Aircraft Cabin Air Conference: Conference Proceedings*. London: GCAQE. Available from: https://doi.org/10.5281/zenodo.6442960

Citation of an individual article in the proceedings (ISO 690):
LASTNAME, FirstName, 2021. ArticleTitle. In: SCHOLZ, Dieter, MICHAELIS, Susan (Ed.). *2021 International Aircraft Cabin Air Conference: Conference Proceedings*. London: GCAQE. Available from: https://doi.org/10.5281/zenodo.6442960

Independent citation of an individual article (ISO 690):
LASTNAME, FirstName, 2019. *ArticleTitle*. Presented at the 2021 International Aircraft Cabin Air Conference (Online, 15-18 March 2021). Available from: https://doi.org/10.5281/zenodo.xxxxxxx

11 short documentary films were presented during the 2021 International Aircraft Cabin Air Conference. The films are stored for streaming on Vimeo (https://vimeo.com). Access to these films is given in the section "Conference Documentary Films".

Presentation are in a free format, but *Extended Abstracts* and *Conference Papers* were edited in a format defined for the conference (https://CabinAir.ProfScholz.de). Authors were ask to make an attempt and to deliver their manuscript according to the template. All manuscripts went through an **editorial review**. They were subsequently formatted to conference standards by the editor and by students from Hamburg University of Applied Sciences.

Please note: Neither the conference organizer nor the editors can be held responsible for inaccuracies or errors in any document in these proceedings.

Dieter Scholz and Susan Michaelis (Editors)

Introduction to the Conference

The Conference Director Captain Tristan Loraine welcomed delegates to the 2021 Conference and thanked the principal sponsors Pall Aerospace and BASF for their continued support of the conference. Captain Loraine briefly discussed the negative impact of COVID on society and the aviation industry and explained why consequently the conference had moved online.

Conference Documentary Films

Understanding filtration and 'bleed air'
https://vimeo.com/524184853

Differing viewpoints
https://vimeo.com/520900018

GCAQE
GCAQE global 'Clean Air Campaign'
https://www.gcaqe.org/cleanair

Captain Tristan Loraine BCAi
Under reporting and GCARS
https://vimeo.com/368028953

Michaelis et al.
Ultrafine Particle Levels Measured On Board Short-haul Commercial Passenger Jet Aircraft
https://vimeo.com/520013750

GCAQE
One night near Malmo and further research
https://vimeo.com/520042108

Understanding organophosphates used in aviation
https://vimeo.com/520060743

Dr. Mark Montgomery PhD
Human Intoxication Following Inhalation Exposure to Synthetic Jet Lubricating Oil
https://vimeo.com/520896124

Crew exposure - a personal experience
https://vimeo.com/520030089/c7ceb41990

A passenger's perspective of contaminated air
https://vimeo.com/522288761

A journey to the High Court of Australia
https://vimeo.com/520054588

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Alessandra Airaldi:
Flight Safety and the Key Role of Flight Attendants
https://doi.org/10.5281/zenodo.4945788 (Conference Paper, 2 pages)
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Judith Anderson:
Oil Fumes, Flight Safety, and the NTSB
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Frank Brehany:
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Jonathan Burdon et al.:
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Tony Cable:
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Eoin Coates; Kris Major:
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Study on Aircraft Bleed Air Contamination by Engine Oil
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Nicholas McHugh:

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Susan Michaelis:

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Dieter Scholz:
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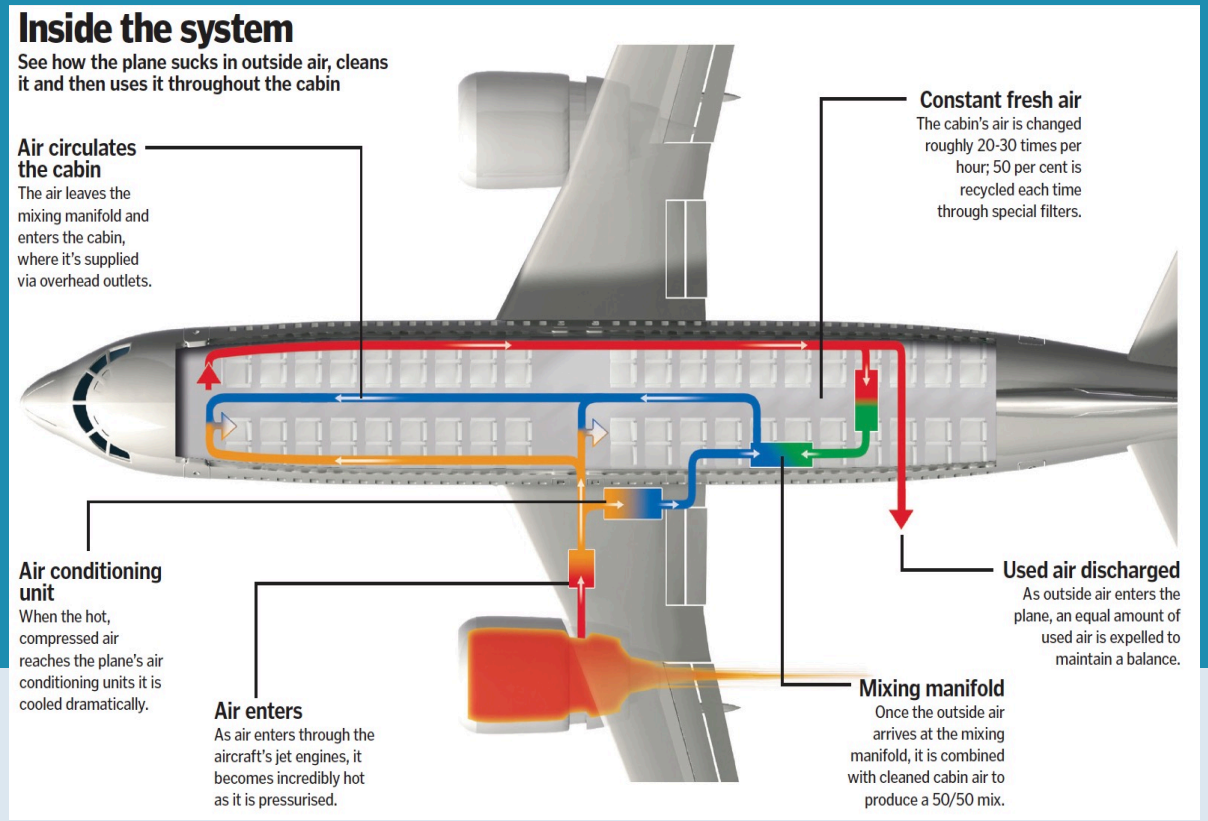
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KU LEUVEN

Cabin Air Contamination Sensors and European Regulations

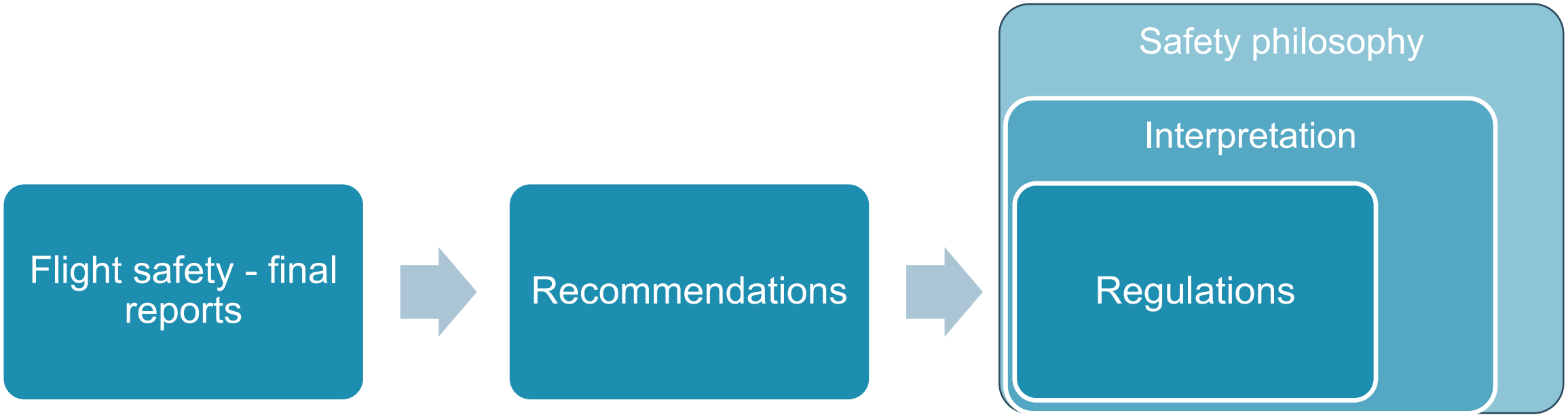
Aircraft Cabin Air International Conference 2021



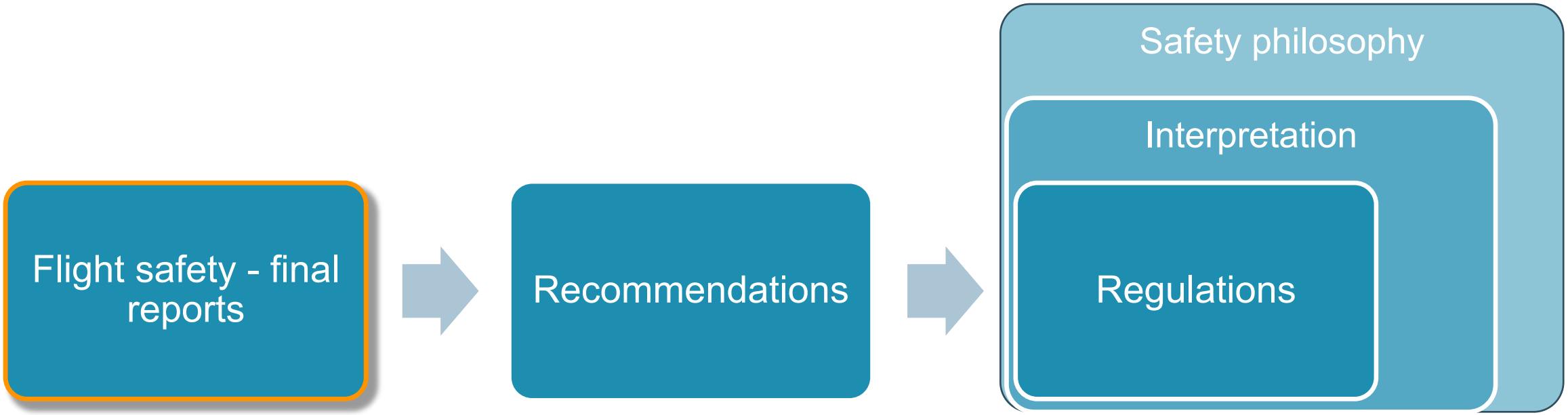
Arie Adriaensen - 15 March 2021

KU Leuven University - Dpt of Mechanical Engineering

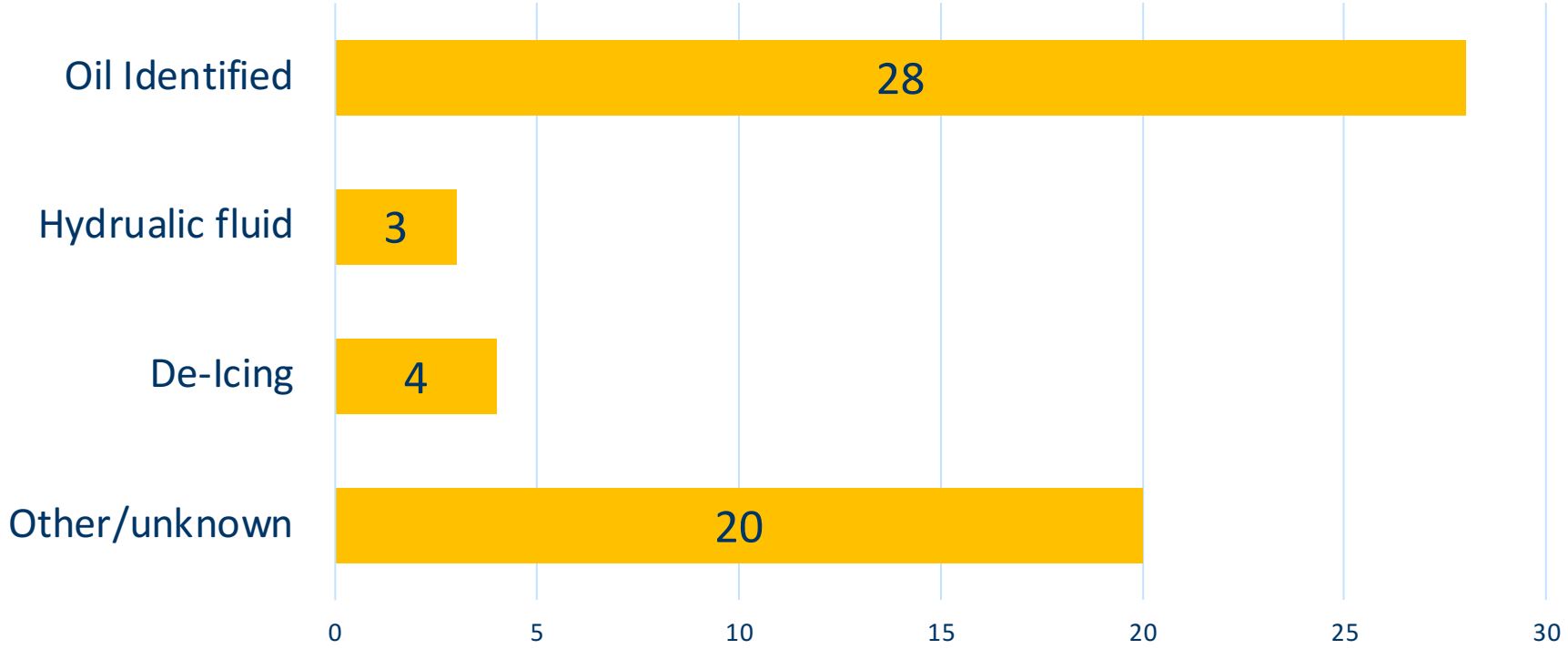
Presentation structure



Presentation structure



Incident Reports Root Causes 1995-2015 [1]



Incident Reports excerpts

AAIB UK

“Smoke or fumes in the flight deck or passenger cabin present the crew with a **potentially hazardous situation, which requires prompt action.** [3]

AAIB UK

“identified **153 reports** of smoke/fumes in addition to the investigated incident on UK fleet over a three-year period, **including 40 reports where exposure had “adverse physiological effects on one or both pilots, in some cases severe**.” [4]

SUST Switzerland

“ **Hydraulic fluids**, as they are used today in commercial aviation, fundamentally pose a **non-negligible risk potential**” [5] [translated]

EASA's interpretation of risk [9]

- "The known reported serious incidents (involving impairment or incapacitation of crews) are rare and the **safety analysis objective for such hazardous event is not put into question**"
- "The Agency is not aware of **any accident (involving injuries or loss of life or substantial aircraft damage)** for which cabin air contamination by engine or APU has been identified as the root cause."
- "Health issues are not within the primary scope of the Agency's mandate. However, the Agency would take action whenever a health case is evidenced by competent health authorities which would require a change in the design of aircraft."
- "The potential safety risk can be mitigated by existing procedures and equipment (including the use of oxygen masks)"

Presentation progress



UK final report recommendation

Safety Recommendation 2007-002 (to EASA) and 2007-003 (to FAA)

> “It is recommended that the EASA consider requiring, for all large aeroplanes operating for the purposes of commercial air transport, a system to enable the flight crew to identify rapidly the source of smoke by providing a **flight deck warning of smoke or oil mist** in the air delivered from each air conditioning unit.” [4]

Austria final report recommendation

Safety Recommendation SE/SUB/LF/10/2016

> “The installation of technical **monitoring** capabilities such as **sensors** that routinely record the composition or possible contamination of the cabin air in the aircraft **in real time and warn the pilots** in due time, coupled with suitable filter systems, **should be mandatory for aircraft that use bleed air** from the engines for the cabin air.” [6] [translated]

Recommendation follow-up

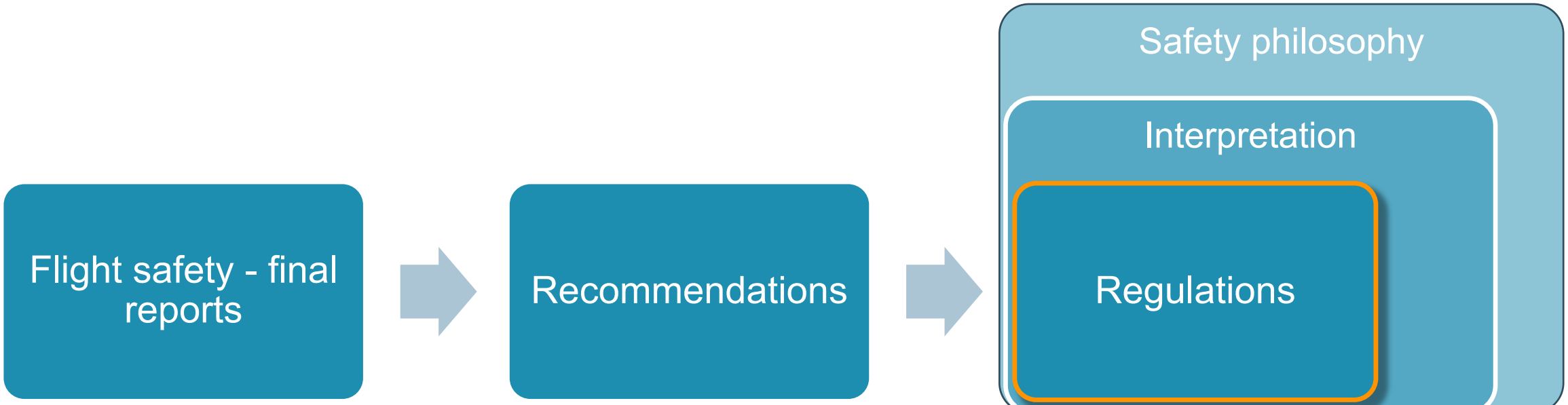
REGULATION (EC) No 216/2008:

> "Results of air accident investigations should be acted upon as a matter of urgency, in particular when they relate to defective aircraft design and/or operational matters, in order to ensure consumer confidence in air transport." [7]

UK AAIB in relation to 2007-002 :

> *"To date, the AAIB has not received formal responses to these recommendations."* [4]

Presentation progress



EASA CS 25.1309(c) - Warning Indication

CS 25.1309(c) requires that "**information concerning unsafe system operating** conditions **must be provided to the crew to enable them to take appropriate corrective action**. Compliance with this requirement includes consideration of crew alerting cues, corrective action required, and the capability of detecting faults." [8]

EASA CS 25.1309(c) - Warning Indication

- “The required information will **depend on the degree of urgency** for recognition and corrective action by the crew. It should be in the form of :
- a **warning**, **if immediate recognition and corrective or compensatory action by the crew is required**;
- a **caution** if immediate crew awareness is required and subsequent crew action will be required;
- an **advisory**, if **crew awareness is required and subsequent crew action** may be required;
- a message in the other cases.” [8]

EASA CS 25.1309(c) - Warning Indication

"Some examples include reconfiguring a system, **being aware of a reduction in safety margins**, **changing the flight plan or regime, or making an unscheduled landing to reduce exposure to a more severe Failure Condition** that would result from subsequent failures or operational or environmental conditions. **Information is also required if a failure must be corrected before a subsequent flight."** [8]

EASA CS 25.1309(c) - Warning Indication

"Some examples include reconfiguring a system, **being aware of a reduction in safety margins**, **changing the flight plan or regime, or making an unscheduled landing to reduce exposure to a more severe Failure Condition** that would result from subsequent failures or operational or environmental conditions. **Information is also required if a failure must be corrected before a subsequent flight.**" [8]

"periodic maintenance or flight crew checks should not be used in lieu of detectors." [8]

EASA definition unsafe condition

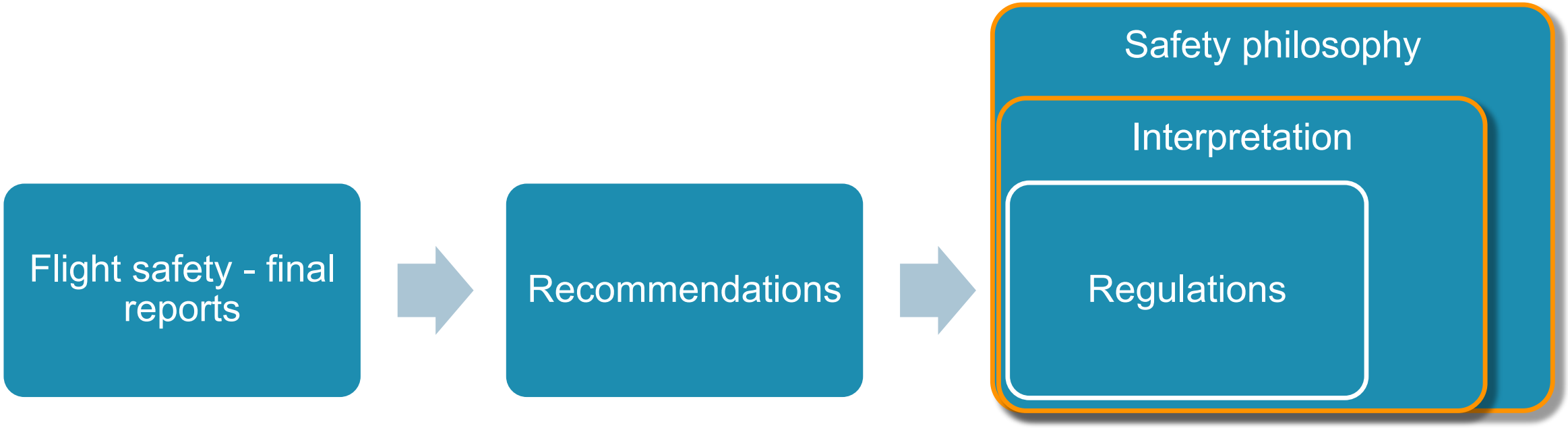
An unsafe condition exists if there is factual evidence (from service experience, analysis or tests) that:

(a) An event may occur that would result in fatalities, usually with the loss of the aircraft, or reduce the capability of the aircraft or the ability of the crew to cope with adverse operating conditions

to the extent that there would be:

- **A large reduction in safety margins or functional capabilities**
- **Physical distress or excessive workload such that the flight crew cannot be relied upon to perform their tasks accurately or completely**" [8]

Presentation structure



Failure probability versus severity [8]

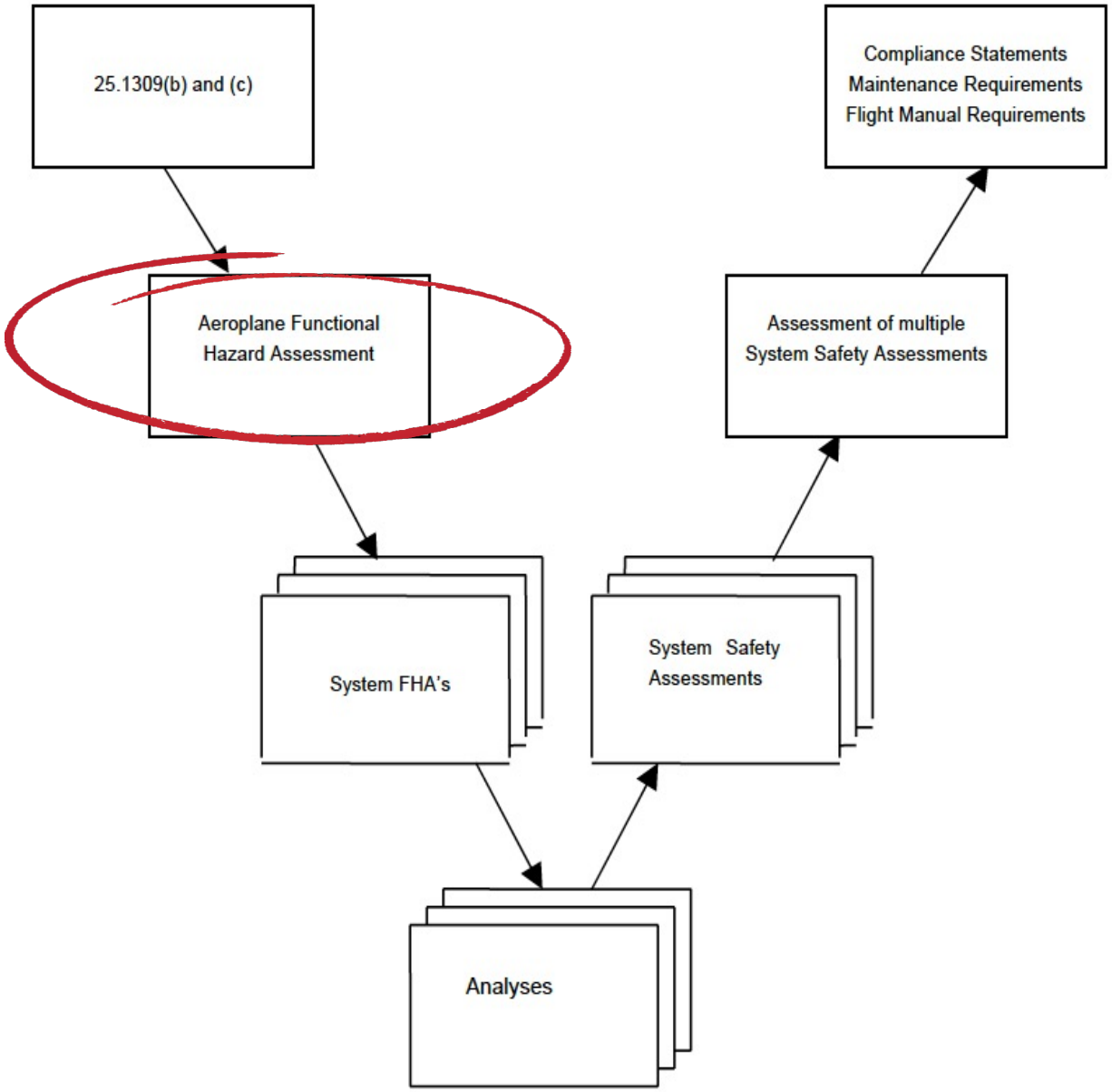
- **Not** for design features that have been shown to negatively affect safety. CS 25.1309(a)
- Systems should perform as intended under all foreseeable operating conditions and **should not pose a danger in themselves.** CS 25.1309(a)
- Effects of failure probability, not accident probability

Effect on Aeroplane	No effect on operational capabilities or safety	Slight reduction in functional capabilities or safety margins	Significant reduction in functional capabilities or safety margins	Large reduction in functional capabilities or safety margins	Normally with hull loss
Effect on Occupants excluding Flight Crew	Inconvenience	Physical discomfort	Physical distress, possibly including injuries	Serious or fatal injury to a small number of passengers or cabin crew	Multiple fatalities
Effect on Flight Crew	No effect on flight crew	Slight increase in workload	Physical discomfort or a significant increase in workload	Physical distress or excessive workload impairs ability to perform tasks	Fatalities or incapacitation
Allowable Qualitative Probability	No Probability Requirement	<---Probable---->	<----Remote---->	Extremely <----------> Remote	Extremely Improbable
Allowable Quantitative Probability: Average Probability per Flight Hour on the Order of:	No Probability Requirement	<----------> $<10^{-3}$ Note 1	<----------> $<10^{-5}$	<----------> $<10^{-7}$	$<10^{-9}$
Classification of Failure Conditions	No Safety Effect	<-----Minor----->	<-----Major----->	<--Hazardous-->	Catastrophic

Note 1: A numerical probability range is provided here as a reference. The applicant is not required to perform a quantitative analysis, nor substantiate by such an analysis, that this numerical criteria has been met for Minor Failure Conditions. Current transport category aeroplane products are regarded as meeting this standard simply by using current commonly-accepted industry practice.

Functional Hazard Assessment

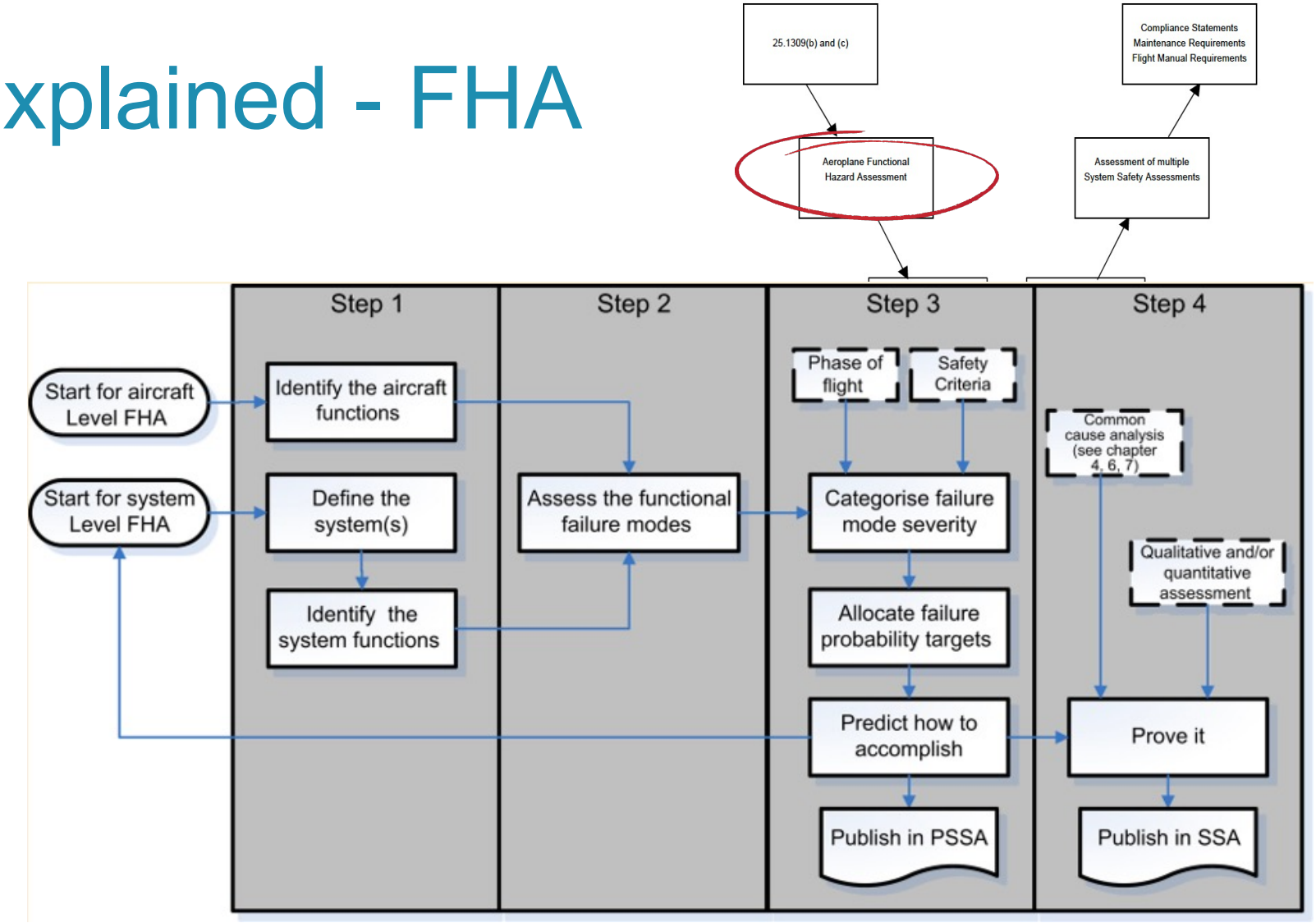
Safety targets without system architecture



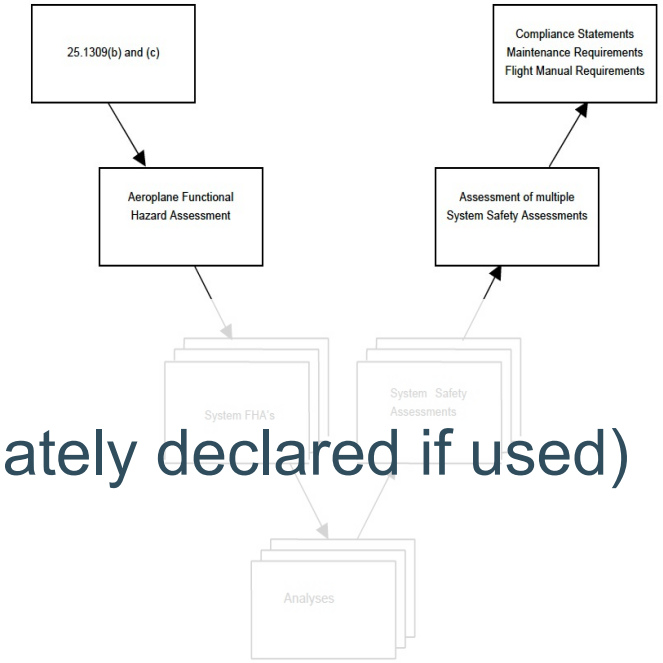
Aviation safety explained - FHA

Aim preliminary functional hazard assessment [10]

- safety objectives of the system relative to the identified functional failure modes
- **not consider the system architecture**
- consider the **worst case effects**



FHA philosophy



"The following factors should be considered (and appropriately declared if used) when determining the severity of a failure condition:

- **time to detection** (i.e. when detected);
- failure recognition provided (i.e. how detected)
- how would the pilot react (i.e. what to do) to cope with the failure and the timeliness thereof" [10]

EASA's interpretation of risk [9]

- "The known reported serious incidents (involving impairment or incapacitation of crews) are rare and the safety analysis objective for such hazardous event is not put into question"
- "The Agency is not aware of any accident (involving injuries or loss of life or substantial aircraft damage) for which cabin air contamination by engine or APU has been identified as the root cause."
- " "Health issues are not within the primary scope of the Agency's mandate. However, the Agency would take action whenever a health case is evidenced by competent health authorities which would require a change in the design of aircraft."
- "The potential safety risk can be mitigated by existing procedures and equipment (including the use of oxygen masks)"

Risk in safety engineering





RISK = probability x severity x detection

Risk in safety engineering



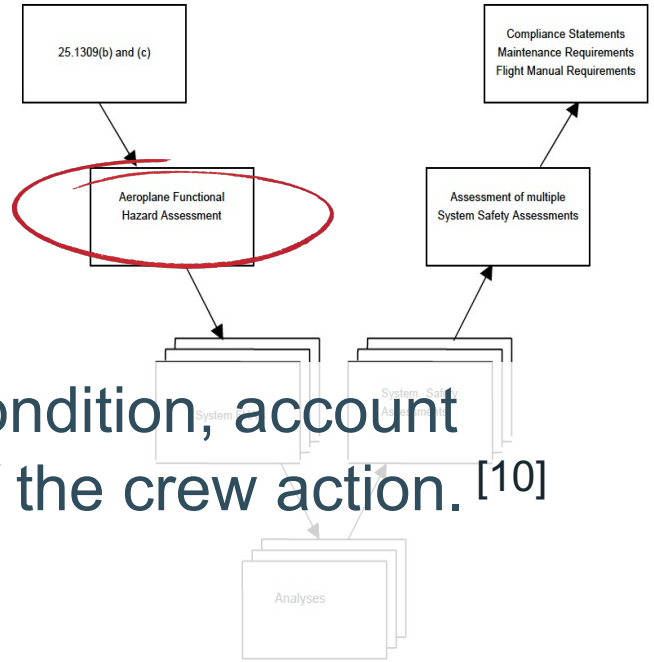




RISK = probability x severity x detection

Crew = detection & system operator

FHA philosophy



- “When assessing the consequences of a given failure condition, account should be taken of the warnings given, the complexity of the crew action. [10]
- Pilots and cabin crews should form an integral part of such discussions as many Safety Assessors have little to no operational experience.” [10]
- “Extensive service experience alone showing that the failure condition has not yet occurred is not sufficient reason to indicate that a single failure condition cannot exist.” [10]

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Flight Safety and the Key Role of Flight Attendants

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Abstract

A cabin crew member reports on the key role of flight attendants in flight safety management.

Keywords

cabin, safety, cabin crew, fume event, contanimant

The Cabin Safety section of the International Civil Aviation Organization website says, “Cabin safety contributes to the prevention of accidents and incidents; the protection of the aircraft’s occupants, through proactive safety management, including hazard identification and safety risk management; and the increase of survival in the event of an emergency situation.” (ICAO 2021).

Cabin crew members are qualified staff who play an important proactive role in managing safety before passengers boarding, during the flight and after disembarking, cabin crew are primarily focused on the prevention of accidents. The safety role of the cabin crew is voluntarily not always blatant because a key part of our job involves the so called “Emotional labor”, in few words we need to be able to manage our feelings and our expressions when we work, especially during interactions with customers and co-workers. This is part of our training on crowd management for example. When we welcome our customers, we are trained to immediately start to evaluate their behavior especially of those sitting in the emergency rows, because we always need to be prepared for a sudden safety occurrence which may need passengers help or preventing unlawful interference and managing passenger events that can compromise safety and security of the flight, such as hijackings. Cabin crew role is not only key to preventing incidents from escalating in the cabin but it includes also being able to adequately inform the flight crew of abnormal situations observed in the cabin or relating to the aircraft, such as pressurization problems or engine anomalies.

In 2019 during their annual conference presentation, ICAO recommended some key publications to stakeholders with the aim to highlight some possible safety threats and errors, risk scenarios and aircraft accidents also affecting the cabin crew’s safety area of competence, one of this is the Circular 344 titled Guidelines on Education, Training and Reporting Practices related to Fume Events, published back in 2015 (ICAO 2015). The flight safety implications of crew members' exposure to oil fumes sourced to the aircraft air supply system, are proven to be highly dangerous that’s why the ICAO has developed guidance material to improve awareness and training of all crew, related to the management of fume events. At any airline level in fact any deficiencies and/or unserviceability of safety equipment or

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systems must always be reported to enable appropriate mandatory reporting to be made. It is in the interests of safety to ensure the full, free and uninhibited reporting of all incidents that affect flight safety.

When it comes to report a fume event, especially when there is no strong smell or no clear smoke in the cabin it is always very difficult to file a report. In some airlines cabin crew cannot directly report fume events, even if they might be systemic failing which could easily result in a repeated event. These kind of events that should be addressed with priority have sometimes to follow a very complicated procedure which implies that the cabin crew first speak to the commander who must then contact the head of pilots to seek verification that it is a "red flag" event and then only if this is confirmed the cabin crew can report the issue with such a priority. Most fume events that are contaminated air smell with no visible fumes then finish to be almost never reported - probably this happens 99% of the times. ICAO Guidelines on Education, Training and Reporting Practices related to Fume Events would recommend that all the crew is trained to recognize, characterize, respond to, and report fume events, without any obstacle, but not every airline has a specific training for cabin crew, nor suitable protective personal equipments.

In my long career now I have unfortunately encountered many crew whose health was affected as a result of exposure to these contaminants in the aviation environment. Some of them have developed chronic breathing difficulties and cognitive impairment, which include the inability to carry out routine tasks: skills you don't want any person to lose, especially any crew member.

There is extensive scientific literature on the toxicological consequences of repeated low dose exposure to chemicals. The health of cabin crew, pilots and passengers has to be put among the priorities, especially now where the Aviation has to be redesigned to face the post pandemic. On existing bleed air architecture aircraft, fugitive emissions from aircraft engines MUST be reduced to the minimum achievable using Best Available Technology (BAT). On future generations of aircraft all the airlines should be united to choose a bleed-free architecture

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About the Author

Alessandra Airaldi is a cabin crew member, specialized in the area of OH&S with her union and at a regional level, and one of the board members of the GCAQE, the global coalition of health and safety advocates committed to raising awareness and finding solutions to poor air quality on commercial aircraft.

FLIGHT SAFETY AND THE KEY ROLE OF FLIGHT ATTENDANTS



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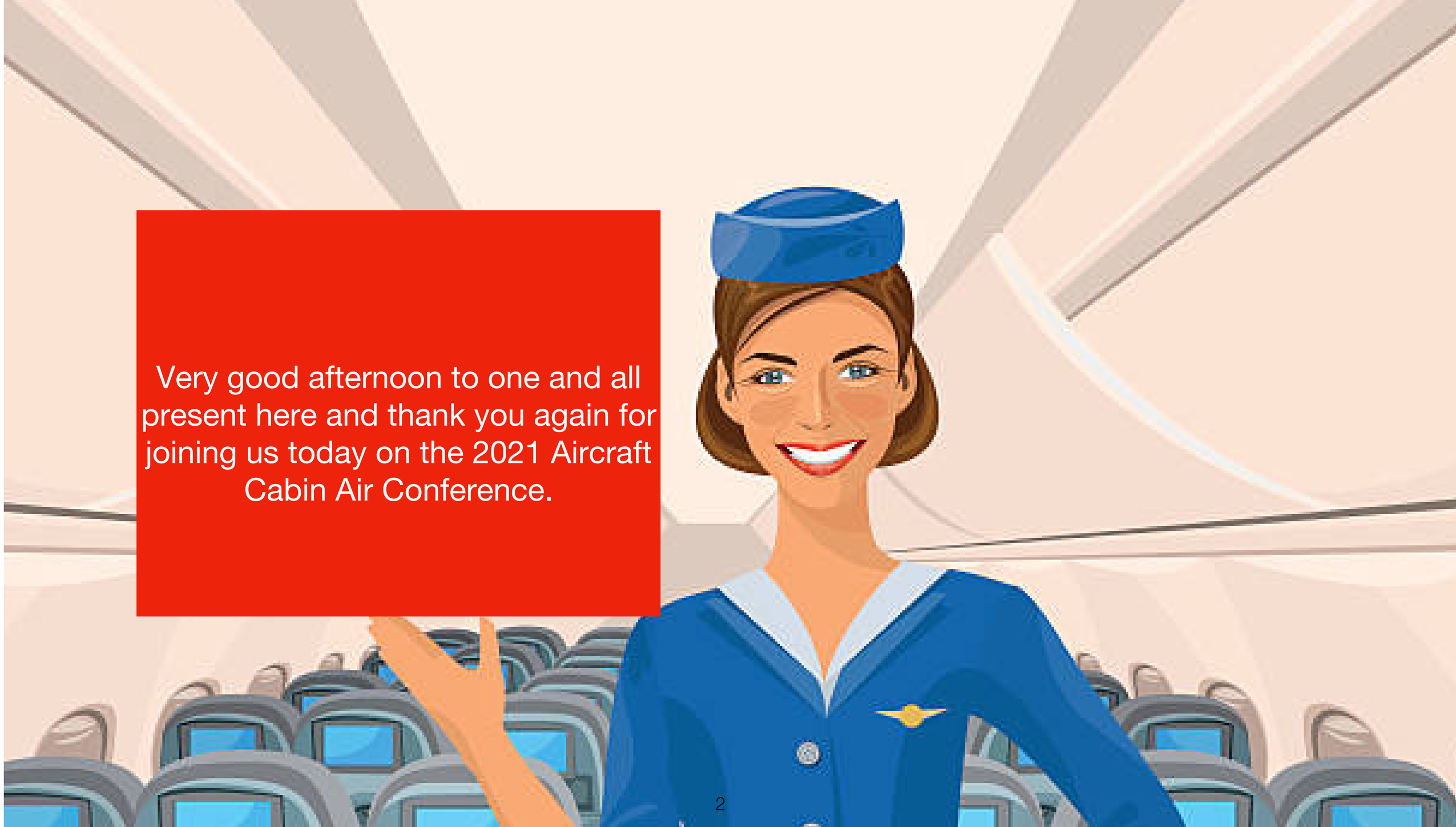
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HAW HAMBURG

ESA European Sealing Association e.V.

By Alessandra Airaldi


Very good afternoon to one and all present here and thank you again for joining us today on the 2021 Aircraft Cabin Air Conference.

GCAQE

Global Cabin Air Quality Executive

Aerotoxic Crew Helpline ITALIA

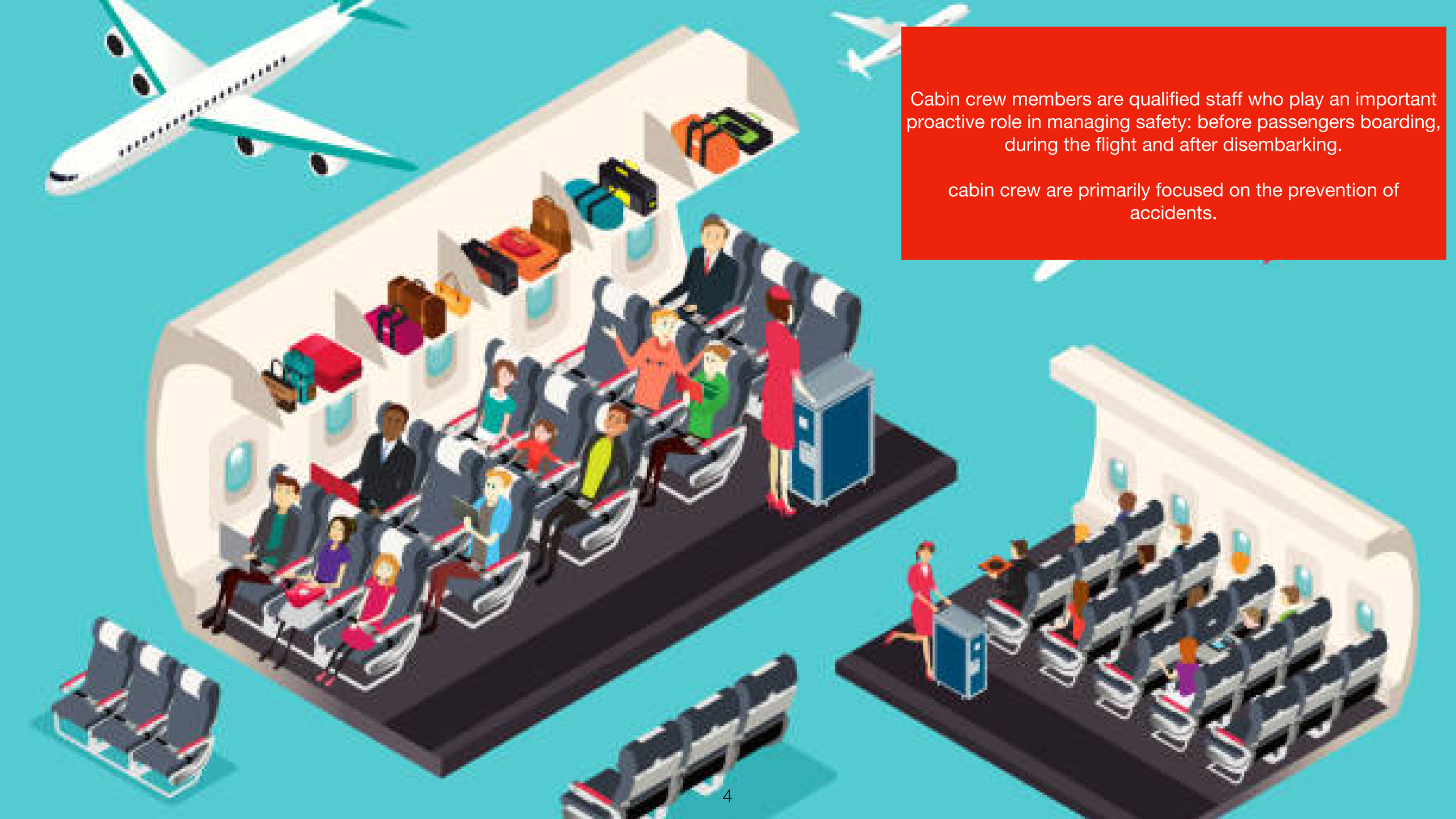


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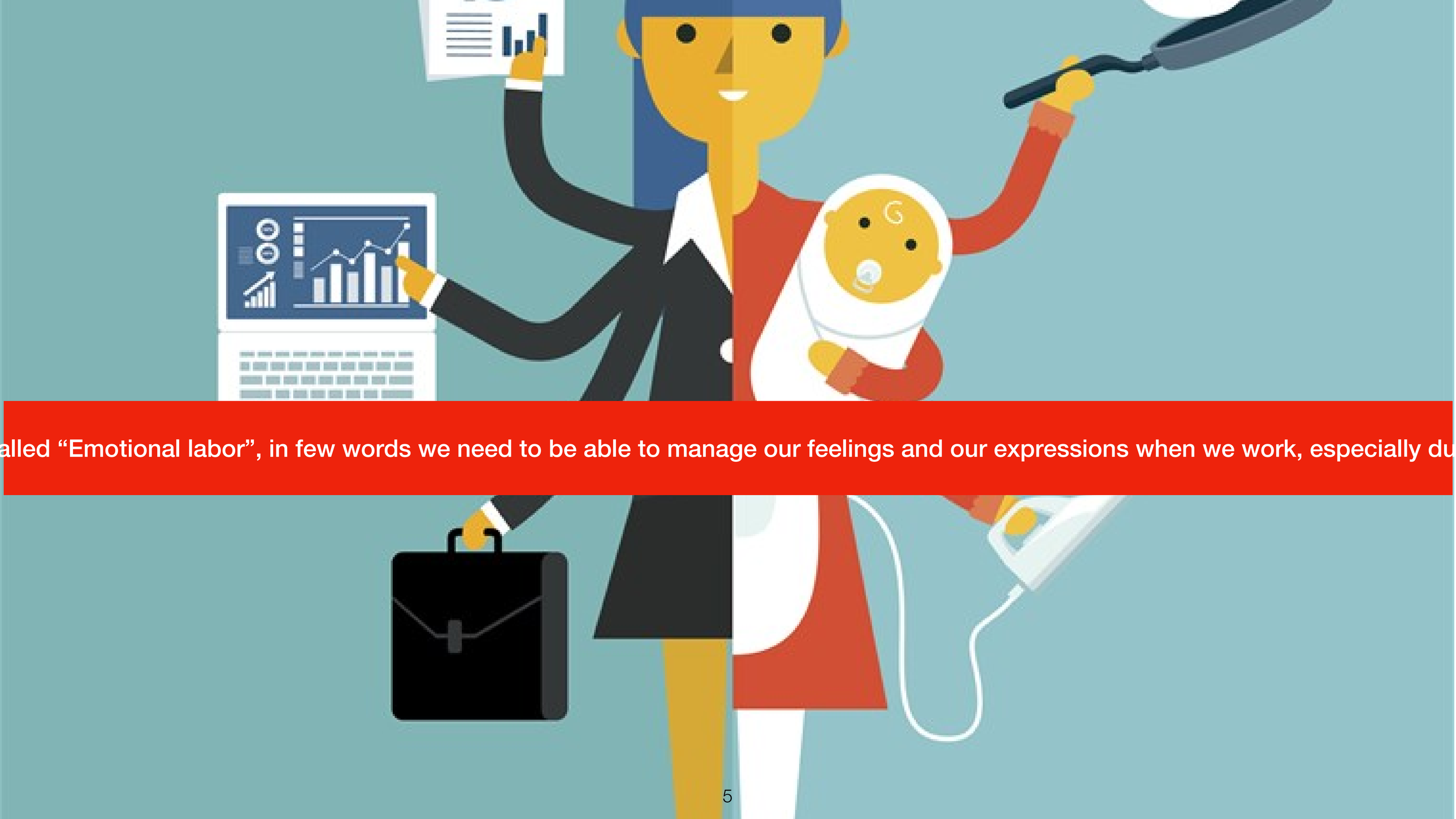
My name is Alessandra Airaldi, I am a Cabin crew member, specialized in the area of OH&S with my union and at a regional level
and I'm one of the board members of the
GCAQE, the global coalition of health and safety avocates committed to raising awareness and finding solutions to poor air quality on commercial aircrafts.

Im here today to introduce you to the key role of the flight attendants in the flight safety management.

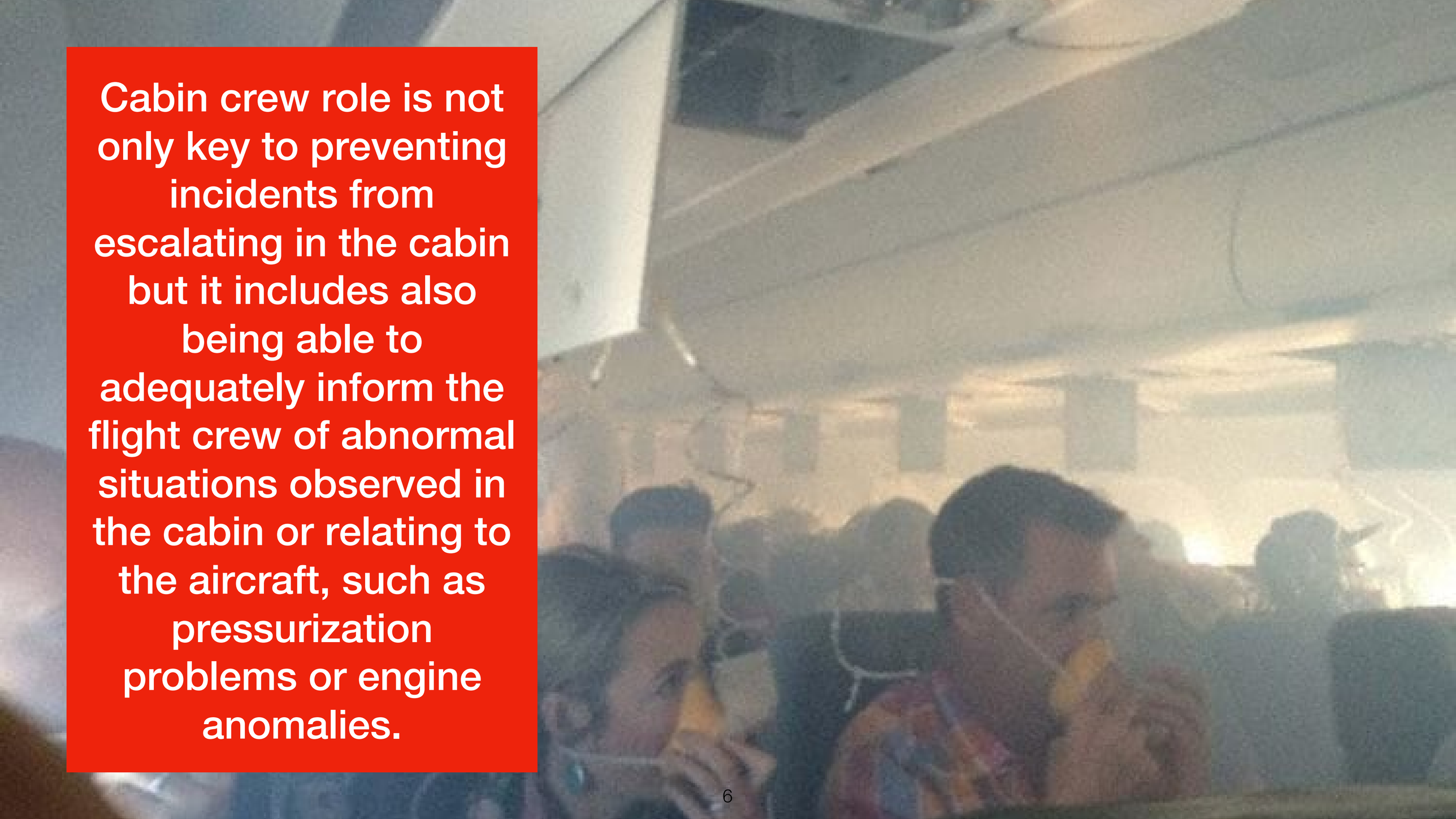


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The flight safety implications of crew members exposure to oil fumes sourced to the aircraft air supply system, are proven to be highly dangerous that's why the ICAO has developed guidance material to improve awareness and training of all crew, related to the management of fume events.

At any airline level in fact any deficiencies and/or unserviceability of safety equipment or systems must always be reported to enable appropriate mandatory reporting to be made.

GCARS

Global Cabin Air Reporting System

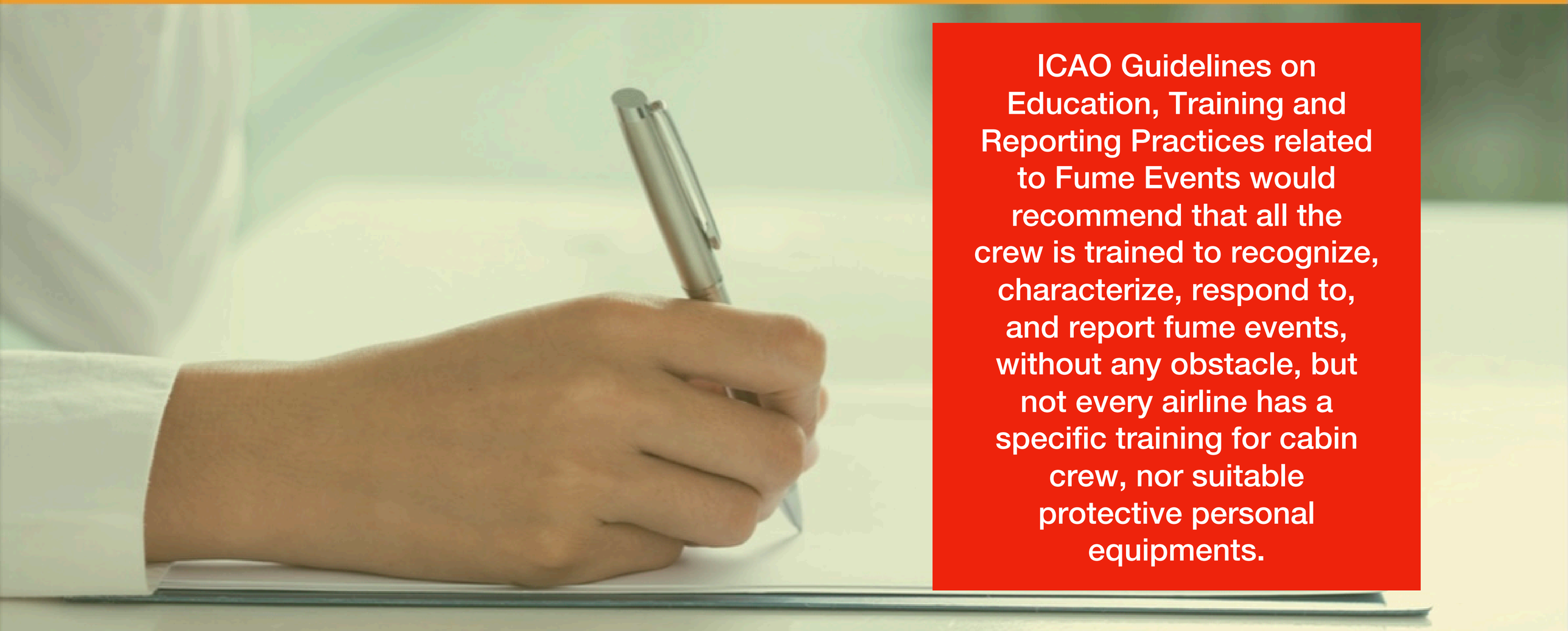


It is in the interests of safety to ensure the full, free and uninhibited reporting of all incidents that affect flight safety.



Most fume events, that is contaminated air smell with no visible fumes then finish to be almost never reported - probably this happens 99% of the times.

Guidelines on Education, Training and Reporting Practices related to Fume Events



ICAO Guidelines on Education, Training and Reporting Practices related to Fume Events would recommend that all the crew is trained to recognize, characterize, respond to, and report fume events, without any obstacle, but not every airline has a specific training for cabin crew, nor suitable protective personal equipments.

Thank you again for joining us today & please do spread the word and fly informed.

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Article

Oil Fumes, Flight Safety, and the NTSB

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Abstract: During its investigations into a series of ten aircraft crashes from 1979 to 1981, US National Transportation Safety Board (NTSB) officials were presented with a hypothesis that "several" of the crashes could have been caused by pilot impairment from breathing oil fumes inflight. The NTSB and their industry partners ultimately dismissed the hypothesis. The authors reviewed the crash reports, the mechanics of the relevant engine oil seals, and some engine bleed air data to consider whether the dismissal was justified. Four of the nine aircraft crash reports include details which are consistent with pilot impairment caused by breathing oil fumes. None of the tests of ground-based bleed air measurements of a subset of oil-based contaminants generated in the engine type on the crashed aircraft reproduced the inflight conditions that the accident investigators had flagged as potentially unsafe. The NTSB's conclusion that the hypothesis of pilot incapacitation was "completely without validity" was inconsistent with the evidence. Parties with a commercial conflict of interest should not have played a role in the investigation of their products. There is enough evidence that pilots can be impaired by inhaling oil fumes to motivate more stringent design, operation, and reporting regulations to protect safety of flight.

Keywords: aircraft; accident; flight safety; fumes; engine oil; hydraulic fluid

check for updates

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1. Introduction

With the exception of the Boeing 787, commercial and military aircraft are designed to "bleed" (or extract) ventilation air, either off the main aircraft engine compressors or from an auxiliary compressor when the aircraft is on the ground. This hot compressed "bleed air" is then cooled, dehumidified, typically mixed with some fraction of recirculated air, and routed to the cabin and flight deck for ventilation and pressurization [1]. To greater or lesser degrees—engine oil can contaminate the compressed air, whether it migrates across engine seals, spills from an overserviced reservoir, or is vented improperly, for example [2]. The problem with this design is that a fraction of that compressed air is then bled off the engine and routed to the air conditioning system for cabin ventilation and pressurization. The "bleed air" stream is not filtered, so oil fumes from the engine can be delivered directly to the occupied zones of the aircraft.

Concerns about aircrew exposure to either suspected or confirmed bleed-sourced fumes inflight have been raised globally since the 1930s on all types of aircraft [3–13]. One of the early references to pilots breathing "hot oil fumes" inflight acknowledged that "the symptoms in these cases have been similar to those of carbon monoxide poisoning," but noted that various aldehyde breakdown products are "probably the causative agents," which the author describes as present at concentrations that are "obviously sufficient to be dangerous to safety inflight" [14] (pp. 178–180).

Within this history, there are two documents which explicitly refer to fatal accidents associated with pilot impairment caused by oil-contaminated bleed air. One of those documents refers to "several unexplained fatal crashes involving single pack, carrier-based,

turbine-powered aircraft . . . attributed (rightly or wrongly) to contaminated engine bleed air" [15] (p. 1). In response to those crashes, the United States (U.S.) Air Force, Navy, and manufacturers apparently "initiated efforts to resolve the contamination problem" [15] (p. 1). The other document describes an investigation by the U.S. National Transportation Safety Board (NTSB) conducted in response to ten crashes on privately-operated turboprop planes, all equipped with the Garrett TPE331 engine [16]. NTSB investigators had hypothesized that "several" of the crashes could have been the result of the pilots being impaired by breathing oil fumes inflight. The suggested source of the oil fumes was a cracked front main shaft compressor carbon seal in the engine. In response, the NTSB initiated ground-based engine testing to assess what the pilots may have inhaled [16]. In conjunction, the U.S. Federal Aviation Administration (FAA) exposed test animals to oil fumes and observed the physiological effects [17]. Ultimately, the NTSB and their industry partners dismissed the hypothesis that inhaling oil fumes could have impaired any of the pilots [16]. The authors reviewed the evidence to determine if the dismissal was supported by the evidence that was available at the time. The authors also reviewed the relevant aviation regulations in the United States to consider whether they are sufficient to prevent inflight exposure to oil fumes.

2. Materials and Methods

Between August 1979 and April 1981, ten private aircraft, each outfitted with Garrett TPE331 engines lubricated with Exxon 2380 oil, crashed. The dates, location, aircraft types, and registration numbers are listed in Table 1, reproduced from the NTSB investigative reports [16].

Table 1. Accidents investigated for pilot incapacitation.

Crash No.	Date (yyyy-mm-dd)	Location	Aircraft Type	Registration No.
1	1979-08-03	Hays, Kansas	Mitsubishi MU-2B	N208MA
2	1979-11-01	Nashville, Tennessee	Mitsubishi MU-2F	N8730
3	1979-12-21	Provo, Utah	Mitsubishi MU-2B-20	N2-OBR
4	1980-01-11	Atlantic Ocean	Cessna 441	N441NC
5	1980-02-14	Near Houston, Texas	Mitsubishi MU_2B-35	N346MA
6	1980-02-23	New Orleans, Louisiana	Mitsubishi MU-2-40	N962MA
7	1980-12-06	Ramsey, Minnesota	Mitsubishi MU-2-40	N969MA
8	1980-12-15	Richmond, Indiana	Mitsubishi MU-2B-30	N93UM
9	1981-01-07	Burns, Oregon	Aero Commander 690B	N81521
10	1981-04-22	Alpena, Michigan	Mitsubishi MU-2B-20	N9JS

The authors searched online NTSB databases for the crash reports, nine of which were fatal accidents and one of which was a serious incident. The crash reports were only available on microfilm and, because of the COVID-19 pandemic, the NTSB library which houses microfilm reports was closed. Instead, the authors were able to purchase nine of the ten crash reports through a private company (General Microfilm, West Virginia). The remaining report was unavailable. Additional details of the 10 crashes are listed in Table 2.

The authors researched the design of the Garrett TPE331 engine and the associated potential for bearing and seal failures which could cause oil fumes to contaminate the bleed air supply.

The authors reviewed the NTSB investigative report which described the results of bleed air quality engine testing for selected oil-based contaminants in the bleed air supplied by a Garrett TPE331 engine with and without oil contamination [16]. The test protocol had been designed to "investigate the hypothesis that toxic or anesthetic gases could be generated from engine oil that leaked into the engine airflow through a broken seal and that these gases might adversely affect the crew's capacity to control the aircraft during critical phases of flight" [16] (p. 8). Key features of the bleed air tests are listed in Table 3.

Table 2. Additional details of ten accidents investigated for pilot incapacitation.

Crash No.	NTSB Report No.	Flight Phase, Time of Day, Weather	Pilot Age (Years), Flight Time (h)	Probable Causes/Factors (per NTSB)	No. Deaths ***
1 **	MKC79FA046	cruise, night, "clear"	34; 2168.	Forward main shaft bearing failed; improper inflight decisions; failed to obtain or maintain flying speed.	7
2	IAD80FA007	descent, night, three-mile visibility, dry, light fog	PIC age redacted; 1498. Copilot age redacted; 2521	Pilot-in-command (PIC) misjudged the distance and altitude on final approach; inadequate supervision of flight; failed to use checklist.	5
3	DEN80FA012	approach, night, "visibility was around one mile"	46; 12,833	Inadequate pre-flight preparation or planning; improper Instrument Flight Rules (IFR) operation; misjudged altitude; Pilot could not find runway; aircraft came to rest in water.	2
4 *	IAD80AA018	descent, night, check	47; 8000	Miscellaneous, undetermined; unable to obtain a response from crew; uncontrolled descent; aircraft came to rest in water.	3
5	FTW80FA042	approach, evening, two-mile visibility, rain showers	45; 12,500	Improper IFR operation; altimeter setting incorrect.	4
6 **	FTW80FA048	approach, morning, 0.25-mile visibility, fog	51; hrs. not reported	Improper IFR operation; crashed into water.	7
7 **	CHI81FA010	approach, afternoon, "good" weather	54; 4949	Failed to obtain/maintain speed; icing conditions, including sleet, frozen rain, etc.	5
8	CHI81FEG03	approach, night, dense fog	59; 10,587	Improper IFR operation; icing conditions, including sleet, frozen rain, etc.	0
9 **	SEA81FA015	approach, afternoon, overcast, 15-mile visibility, wind calm	32; 2177	Miscellaneous/undetermined; uncontrolled collision with ground/water.	2
10	CHI81FA051	approach, night, two-mile visibility, light rain, fog	53; 16,766	Improper IFR operation; crash on final approach, 1.6 miles short of runway; cause unknown.	3

* Microfilm report was unavailable for crash #4. ** Details in the reports for crash #1, 6, 7, and 9 are consistent with engine oil fumes as a contributory factor. Additional details are provided in Table 5. *** In all but crash #8, everyone onboard was killed. In crash #8, the pilot and one of two passengers were injured.

Table 3. Key features of engine bleed testing, per the NTSB investigative report [16].

Test No.	Carbon Seal Intact or Missing?	Oil Added to Bleed Air?	Glass Filter in Bleed Air Line?	Reflects Potential Onboard Conditions?
1	intact	No	yes	no
2	intact	No	yes	no
3a–3f	intact	yes; 2–12 lb/hr	yes	no
3g	intact	No	no	no
4	intact	No	yes	no
5a	missing	No	yes	no
5b	missing	yes; "dirty start"	yes	no

The authors reviewed the relevant aviation regulations for U.S.-registered aircraft operated on routine commercial flights (Table 4). Globally, aviation regulations are harmonized, so most of these regulations are the same in other countries. This is especially true for design and construction-related regulations which are classified under Part 25 of the Federal Aviation Requirements in the United States and as CS-25 (Certification Standards) in Europe, published by the European Union Aviation Safety Agency (EASA).

Table 4. U.S. aviation regulations relevant to air quality on routine commercial flights.

Regulation	Design/Operation	Description
14 CFR § 25.831(b) * "Ventilation"	Design	"The aircraft air supply system must be designed to ensure that crew and passenger compartment air [is] free from harmful or hazardous concentrations of gases or vapors."
14 CFR § 25.831(b)(1)"Ventilation"	Design	The carbon monoxide concentration in the cabin and flight deck supply air must not exceed 50 ppm.
14 CFR § 25.1309(c) "Equipment, systems, and installation"	Design	"Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and associated monitoring and warning means must be designed to minimize crew errors which could create additional hazards."
14 CFR § 121.703(a)(5) "Service difficulty reports"	Operation	Airlines "shall report the occurrence or detection of each failure, malfunction, or defect concerning . . . [a] aircraft component that causes accumulation or circulation of smoke, vapor, or toxic or noxious fumes in the crew compartment or passenger cabin during flight."
14 CFR § 121.705"Mechanical interruption summary report"	Operation	Airlines shall report each "interruption to a scheduled flight," such as a diversion, cancellation, or tail swap, caused by known or suspected mechanical difficulties or malfunctions that are not required to be reported under the 14 CFR § 121.703.
FAA Order 8020.11D (Chapter 6 and FAA Form 8020-23)	Operation	Airlines shall report accidents and occurrences which are associated with the operation of an aircraft and affect (or could affect) the safety of operation, including smoke/fumes.

* Note that "14 CFR" refers to the Code of Federal Regulations Title 14 which are aviation and aerospace regulations published by the FAA for U.S.-registered aircraft. The symbol "§"is shorthand for "Part" when referring to U.S. regulations. The relevant regulations include "Part 25" (Airworthiness Standards: Transport Category Airplanes) and "Part 121" (Operating Requirements: Domestic, Flag, and Supplemental Operations).

Finally, the authors reviewed some proposals to implement engineering and operational control measures intended to prevent exposure to oil fumes on aircraft.

3. Results

3.1. Accident Reports

For nine of the ten aircraft crashes, the authors were able to obtain the NTSB investigation reports (Tables 1 and 2). The microfilm report for crash number 4 was unavailable. Of these nine crashes, eight were fatal accidents (35 people were killed) and one (crash number 8) was a serious incident (the pilot and one of the two passengers were injured). Details in the accident reports for crash numbers 1, 6, 7, and 9 (Tables 1 and 2) suggest that oil fumes were either a contributory or casual factor (Table 5).

Table 5. NTSB accident report details consistent with exposure to oil fumes.

Crash No.	Description of Crash Conditions
1	The NTSB report describes how, when the pilot was en route, at what may have been top of climb, the pilot "reported a loss of oil pressure in the right engine." At the same time, "the pilot reported smoke and fumes in the cabin." A few minutes later, the pilot reported that he had shut down the right engine. He then stopped communicating with air traffic control and crashed into a field without putting the landing gear down (per witness reports). The subsequent teardown of the right engine "revealed that the forward main shaft bearing had failed."
6	The NTSB report describes how, on approach, the pilot stopped responding to air traffic control. The aircraft descended into a lake and "all aboard perished." The report goes on to say that "[d]uring the course of the investigation, it was reported by various persons that the aircraft had a history of smoke, fumes, and carbon monoxide collecting in the cockpit and cabin area...Examination of the interior of the subject aircraft environmental control system revealed an oily residue in the portion which is supplied by the left engine [with a history of a cracked carbon seal] while that supplied by the right engine was clean."
7	The NTSB report describes how, on approach, the pilot did not respond to air traffic control instructions. Witness reports described how the aircraft came out of the clouds spinning with the nose down and crashed into a field. In the engine tear down report, there were references to "black dirt deposits found throughout the entire gas path of the engine . . . [including] the bleed air ports . . . " The NTSB report stated that the pilot had failed to obtain/maintain speed and the cause of the crash was unknown.
9	The NTSB report describes how ground witnesses observed the aircraft flying away from the airport maneuvering erratically. The aircraft crossed a highway, pitched up steeply, fell, and crashed. The engine tear down was "to determine the condition of the carbon seal and bearing located between the compressor section and gearbox section." The report concluded that "one carbon seal, due to the discoloring of the oil slinger, was leaking some oil past the face." The report also noted that "Bonneville Power maintenance personnel felt the amount of leakage was insignificant," but the basis for their claim and their qualification to make it were not provided.

In addition to the four crashes described in Table 5, crash numbers 5 and 10 (Tables 1 and 2) include details which could be related to oil fumes, although the significance of those details is less clear. Specifically, the NTSB report for crash number 5 describes how, without warning, the aircraft crashed into the trees near the runway on final approach. Another pilot who observed the crash stated: "We feel that the pilot of the MU-2 got disoriented and just flew the airplane into the ground." The autopsy report for the pilot reported 5% carboxyhemoglobin in his blood. The NTSB report for crash number 10 describes how the aircraft crashed on final approach, after which the engine manufacturer performed the engine tear down to determine if oil fumes played a role in the crash. The manufacturer concluded that there was "no indication" of anything other than

normal engine operation and they attributed the engine compressor carbon seal damage to impact. The Civil Aeromedical Institute (CAMI) toxicology lab (the research arm of the FAA) tested a component of the air supply system from the aircraft and found a "trace quantity of petroleum base constituent," although the significance of that finding is not clear.

3.2. Description of the TPE331 Engine and Seal Assembly

The Garrett TPE331 is a fixed-shaft constant-speed turboprop engine (Figure 1). Its gas turbine consists of a compressor, combustion chamber, and turbine. Ambient air is directed to the compressor section through the engine inlet. A two-stage centrifugal compressor increases air pressure and directs it to the combustion chamber. In the combustion chamber, fuel is added to the air through the fuel nozzles. On engine start-up, the gas mixture is ignited by igniter plugs. In a normal operation the igniter is not in use because the combustion is self-sustained. The hot and high-velocity combustion gases flow through the turbine rotors, where the energy of the gases is converted to torque exerted on the main shaft (A in Figure 1). The reduction gear is designed as a planetary gear on the propeller shaft (B in Figure 1). It converts the low torque (at high rpm) of the main shaft to high torque (at low rpm) on the propeller shaft and drives the propeller. The combustion gases leave the turbine to the atmosphere via the exhaust.

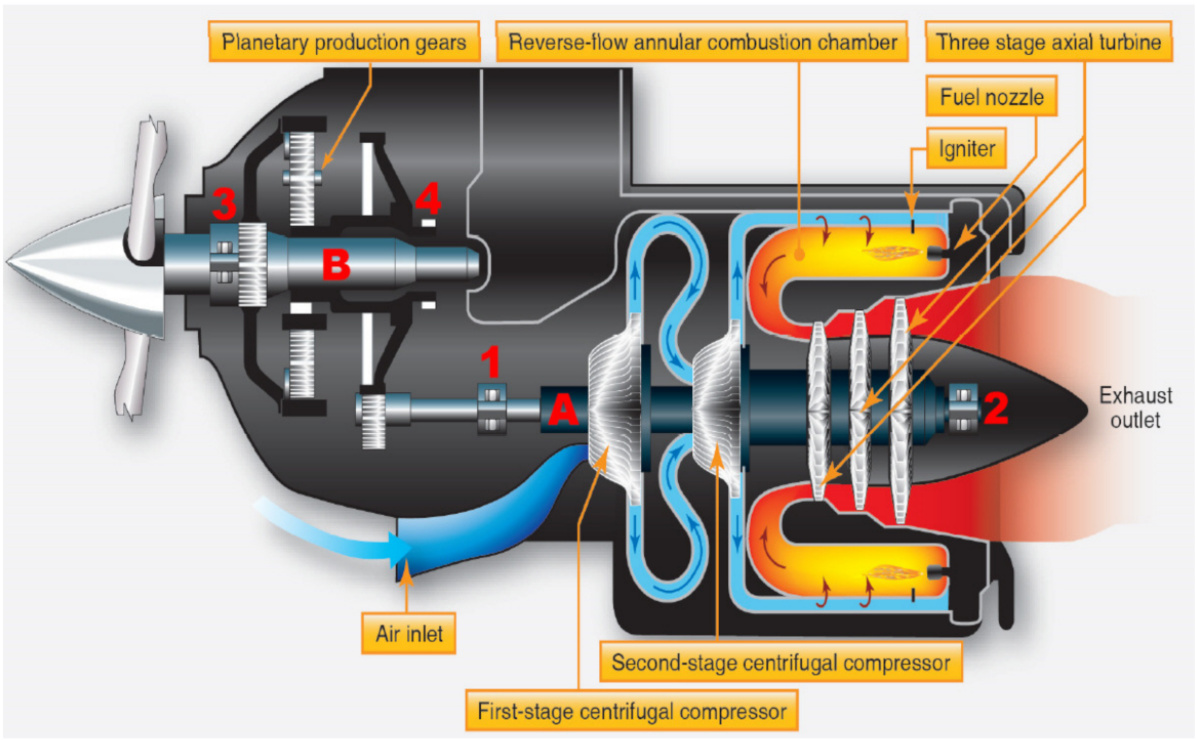


Figure 1. Garrett TPE331 turboprop engine (based on [18], p. 15-3). A. main shaft (engine shaft) with the gas turbine. B. propeller shaft with the reduction gear. 1,2. bearings that support the main shaft. 3,4. bearings that support the propeller shaft. 1. compressor bearing.

The TPE331 is called a fixed-shaft engine because the propeller is firmly connected to the gas turbine. The constant-speed engine maintains its speed by a governor on the propeller. The propeller shaft rotates at a constant speed of 1591 rpm in cruise flight. The main shaft of the engine rotates at a constant speed of 41,730 rpm. Power changes are made by increasing the fuel flow (which increases the torque) rather than the engine speed.

Most of the air (70%) passing through the engine provides internal cooling. Only about 10% of the air that passes through the engine is actually used in the combustion process. Up to approximately 20% of the compressed air may be bled off for the purpose of heating, cooling, cabin pressurization, and pneumatic systems [18], which appears to

be within the average range for other engine types [2]. If the bleed air is contaminated with oil fumes, then the air in the cabin is also contaminated. Normal bleed air pressure is approximately 157 psi (10.82 bar) and the temperature is 360 °C in cruise flight [16].

The engine shafts are supported by rolling bearings. The compressor bearing (1 in Figure 1) is a ball-bearing (Figure 2). The same is true for bearings 2 and 3 in Figure 1.



Figure 2. A typical ball-bearing [19].

The engine cutaway drawing is given in Figure 3 and a detail of that picture enlarged is given in Figure 4.

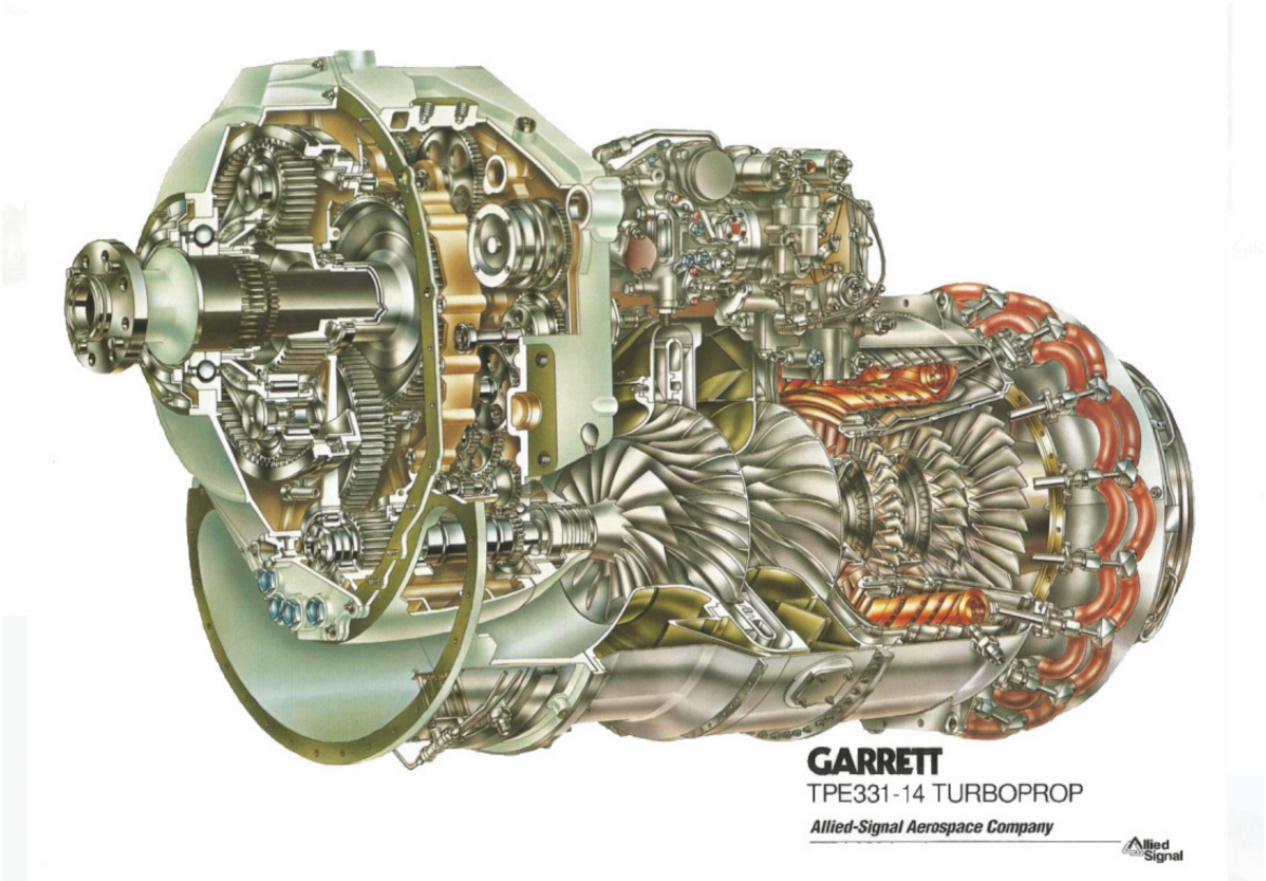


Figure 3. Garrett TPE331 turboprop engine cutaway drawing [20].

In the TPE331 front main shaft compressor seal assembly, two seals are used, acting in series. They prevent the escape of the engine lubricant present in the reduction gearbox via the main shaft and through the compressor bearing into the compressor (Figure 4). The following detailed explanations are reproduced with text elements from [16]:

"First, a mechanical (carbon) seal is provided to prevent leakage if operating oil pressures exceed normal pressures and to prevent potential leakage that might occur during engine

shutdown. The mechanical seal potentially is subject to wear and damage" [16] (p. 2). "When the engine is shutdown, oil drains from the engine walls which increases the oil level above the shaft installation level of the compressor front main shaft; without a mechanical seal, the oil would leak from the reduction gearbox, out the engine inlet and onto the ground. Therefore, a mechanical (carbon-element) seal is necessary to prevent oil leakage when the engine is not operating" [16] (p. 33). This is illustrated in Figure 5.

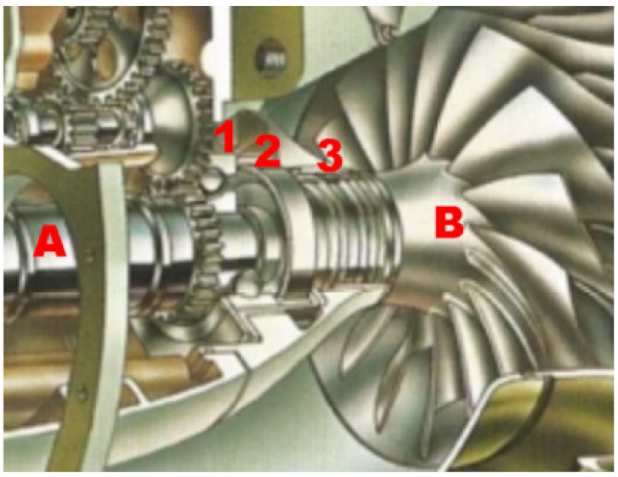


Figure 4. Garrett TPE331 turboprop engine cutaway drawing (detail based on [20]). A. main shaft. B. first-stage centrifugal compressor. 1. compressor bearing (a ball-bearing). 2. carbon seal. 3. labyrinth seal.

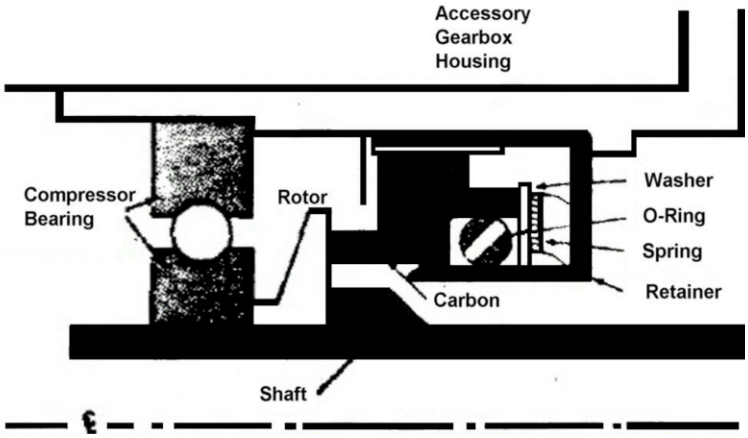


Figure 5. Mechanical (carbon) seal assembly next to the main shaft compressor bearing on the TPE331 engine (based on Figure 3 in [16]).

"Secondly, the TPE331 has a pressurized knife-edge labyrinth air seal that is specifically designed to prevent passage of air/oil mist from the reduction gearbox into the compressor chamber during engine operation" [16] (p. 2). "This pneumatic-type seal is pressurized to approximately 26 psi (1.79 bar) at the inner knife edges. When the engine is operating, the pneumatic seal is independently capable of preventing the air/oil mist from passing out of the reduction gearbox because of a flow of pressurizing air from the seal into the reduction gearbox. However, the labyrinth seal has no sealing capability to prevent engine oil from exiting the reduction gearbox when the engine is not operating and, therefore, requires a mechanical seal to prevent oil leakage when the engine is shut down. The symptom of a failed mechanical seal is oil leaking past the labyrinth seal and running out the engine inlet onto the ground when the engine is not operating" [16] (p. 35). The bleed air passage directs sealing air from the compressor to the labyrinth seal. All of this is illustrated in Figure 6 and additional details are shown in Figure 7.

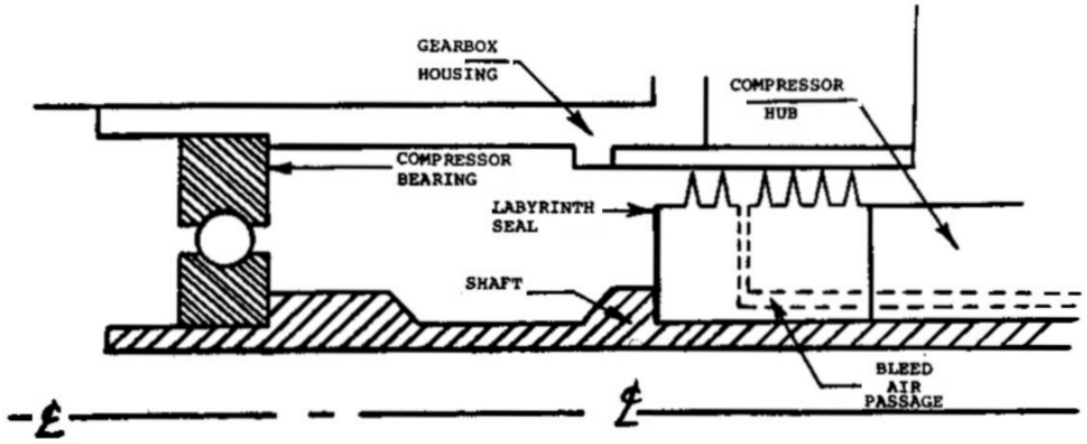


Figure 6. Labyrinth seal close to the main shaft compressor bearing (based on Figure 11 in [16]). Note: The carbon seal is located in between the compressor bearing (**on the left**) and the labyrinth seal (**on the right**) in the empty space but is not shown in this figure.

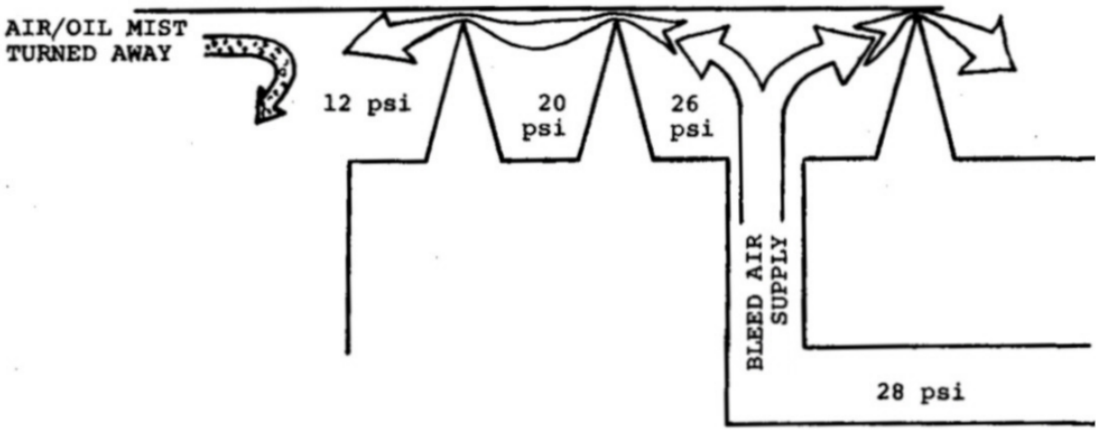


Figure 7. Flow through the labyrinth seal in the TPE331 engine next to the compressor bearing and resulting pressure. The flow to the left pushes back the oil that still comes through the carbon seal (based on Figure 13 in [16]).

"The pressure balances that are maintained may be clearly understood by considering that the chamber containing the air/oil mist operates at approximately 12 psia (−2 psig) while the center of the labyrinth is pressurized to 26 psia (+12 psig). Since air will always flow from a higher pressure area to a lower pressure area, air will flow outward from the center of the labyrinth. Each of the knife-edges operates with only slight clearance from the outer wall, resulting in a high local velocity as the air crosses into the next chamber. With a high local velocity, the air/oil mist cannot flow past the knife edges and enter the compressor air flow" [16] (p. 36). This is illustrated in Figure 7.

"In addition to the labyrinth seal, there are two other pneumatic sealing actions incorporated in the oil containment design of the TPE331 engine ... [First, there is] a negative pressure of approximately 2 psi inside the reduction gearbox with respect to atmospheric conditions. This is accomplished by pumping the oil out of the reduction gearbox at a rate twice that at which it is being pumped in. (Nine gallons per minute in, versus 18 gallons per minute out.) The extra nine gallons pumped per minute is air and this creates a negative pressure (slight vacuum) in the reduction gearbox. If the mechanical seal should fail, the overscavenging will draw air into the reduction gearbox and will prevent the air/oil mist from flowing out ... Secondly the negative pressure effect is supplemented by raising the pressure in the chamber on the air side of the mechanical seal to a positive six psi above ambient" [16] (p. 36). This higher pressure is produced by the centrifugal compressor.

3.3. Bleed Air Testing

In July 1981, the NTSB and a team of government and industry partners formed an "Ad Hoc Investigative Committee" to respond to the hypothesis that oil fumes could contaminate pilots' breathing air through the main shaft compressor carbon seal in the Garrett TPE331 turboprop engine. All the crashed aircraft flew with this engine type. The team proposed to measure selected gaseous contaminants (carbon monoxide, carbon dioxide, nitrous oxides, and total hydrocarbons) in the bleed air produced by that engine type. The goal was to attempt to reproduce the conditions on the crashed aircraft to determine whether the pilots could have been subjected to toxic or anesthetic gases sufficient to impair their ability to operate the aircraft.

Because oil leakage through the carbon seal was the suspected source of oil fumes in the bleed air, selected gaseous contaminants were measured in the bleed air downstream of the compressor, first through an intact seal and second with the seal removed (considered worst-case), during conditions that ranged from no oil to 12 pounds of oil per hour (lb/hr).

The sampling methods were developed by the Exxon Research and Engineering Company and the test conditions, summarized in Table 3, were performed on an engine test stand at the Garrett Turbine Engine Company. During two of the tests, oil mist samples were also collected and analyzed. Largely though, gases were sampled because the investigators "expected that particulate matter would not form" [16] (p. 9).

3.3.1. Primary Bleed Air Testing Conditions

The key features of the 12 primary engine bleed testing conditions, as described in the NTSB report [16] are summarized in Table 3. Additional salient details of the engine bleed testing are summarized in Table 6.

Table 6. Description of TPE331 engine bleed testing, per NTSB report [16].

Trial No.	Description of Sampling Conditions
1–2	These two trials were intended to characterize background levels of contaminants in the bleed air stream. The engine compressor carbon seal was intact, and a glass wool filter was installed in the bleed line. Moreover, oil was not purposefully injected into the bleed air stream.
3a–3f	These six trials were intended to characterize levels of oil-based contaminants in the bleed air stream through an intact engine compressor carbon seal and a glass wool filter. Oil was injected into the bleed air stream for 90 min at a rate of 2–12 pounds per hour while the bleed air was sampled for carbon monoxide, carbon dioxide, nitrous oxides, and hydrocarbons.
3g	This trial was intended to characterize levels of oil-based contaminants in the bleed air stream through an intact engine compressor carbon seal but without a glass wool filter in the bleed stream. The tester injected oil for 15 min, during which time the same gaseous bleed air measurements were made.
4	This trial was intended to simulate the potential for worst-case bleed air contamination by removing the engine compressor carbon seal. Of note, though, a glass wool filter was installed in the sampling line and no oil was injected.
5a	During this trial, the tester did not collect measurements but ran the engine for 10 min and then shut it down to prepare for a "dirty start" in the following test.
5b	During this trial, the engine underwent a simulated "dirty start" which involved internal oil ingestion. The tester measured the concentrations of carbon monoxide, carbon dioxide, nitrous oxides, and hydrocarbons for the first 10 min after the engine was started.

3.3.2. Additional Engine Bleed Air Testing

During two of the oil injection tests (3c and 3f), the tester collected oil mist samples on "membrane filters" which were subsequently analyzed for tricresyl phosphates. The authors of the report noted that no "para or ortho isomers" of tricresyl phosphate were

present above the detection limit [16] (p. 24), although the authors did not define the detection limit or mention the concentrations of meta and mixed meta/para isomers which comprise more than 99% of commercial blends [21].

During tests 1–3, carbon sorbent tubes and impingers were used to collect samples that were subsequently analyzed by GC-MS [16]. The authors stated that these "analyses performed by the Environmental Protection Agency (EPA) [lab] . . . did not lend themselves to meaningful interpretation because of apparent contamination of the samples and lack of parallel quantitation of known compounds . . . " [16] (p. 27). Still, the authors affirmed that "based on the analyses, there was no significant toxicological gaseous content of the TPE331 engine bleed air . . . " [16] (p. 27). The authors also referred to the presence of "a number of compounds in the bleed air under various conditions of the test protocol," but described occupational exposure limits as protective for workers. The report noted that, by comparison, "the concentration of those substances [measured by the EPA] appears to be at such a low level as to cause no acute degradation of pilot performance" [16] (p. 66). Specifically, the authors stated that "it is apparent that toxic effects to aircraft crewmembers would only result from breathing air contamination of sufficient concentrations to cause acute effects" [16] (p. 66).

3.4. Regulations

Aircraft regulations stipulate that the cabin and flight deck ventilation supply systems must be designed to provide air that is "free from harmful or hazardous concentrations of gases and vapors" (14 CFR § 25.831(b)), which includes no more than 50 ppm of carbon monoxide and 5000 ppm of carbon dioxide (Table 4). Moreover, crews must be provided with "warning information" to alert them to unsafe conditions and enable them to take "appropriate corrective action" (14 CFR § 25.1309(c)) (Table 4). To date, though, these regulations have not been applied to monitor contaminants in the cabin air and alert pilots to the presence of oil fumes.

In addition to the design regulations, U.S. airlines are required to comply with three FAA reporting regulations for fume events (Table 4), but all are underutilized [22].

4. Discussion

4.1. Accident Reports

In the investigated crashes (Table 1), eight of the ten aircraft were Mitsubishi MU-2 aircraft. The Mitsubishi MU-2 is a twin-engine turboprop aircraft with a pressurized cabin (Figure 8). The aircraft is known for its difficult handling and high rate of accidents, including fatal accidents [23]. Crash numbers 7 and 8 with this aircraft were in icing conditions which may be relevant, given an Australian Bureau of Air Safety Investigation report on two fatal crashes on MU-2 aircraft, both of which were also in icing conditions [24]. However, even for the 1988 and 1990 fatal crashes in Australia, "icing on the airframe" was only listed as the "probable" cause and, for one of those two crashes, pilot fatigue was also referenced extensively. Thus, the reference to icing conditions in crash 7 in this investigation should be acknowledged but does not rule out cabin air contamination, either as a causal or contributory factor.

Regarding the remaining two crashed aircraft (Table 1), one was a Cessna 441 Conquest II and the other was an Aero Commander 690B. As with the MU-2, each of these is a turboprop aircraft with a pressurized cabin.

In at least four of these ten crashes, there are details which are consistent with impairment caused by oil fumes (Table 5). For each of the crashes, the NTSB identified "probable causes" (including "undetermined"), all of which are reproduced in Table 2. In many cases, though, the "probable cause" is more of a description than an explanation. The real question is, why? Why did the pilot in command "misjudge distance and altitude" or "fail to obtain/maintain speed"? Why was air traffic control "unable to get response from crew"? Was it because these pilots were distracted or fatigued, or were they impaired by fumes?



Figure 8. Mitsubishi MU-2B (Photograph by Alan Lebeda [25], trimmed, GFDL 1.2).

It is tempting to blame crashes on "pilot error," typically attributed to either to inexperience or fatigue. Regarding inexperience, the flight time for the pilots on the crashed planes ranged from 1498 to 16,766 h (average 7999) (Table 2). One analysis estimated that, during the time of these crashes, turboprop pilots logged an average flight time of 528 h per year [26], so if the pilots on the crashed planes reflect this average, they are not novices. Regarding fatigue, the accident reports did not consistently cite either each pilot's total flight time specific to the aircraft type they crashed or the number of hours they flew during the 24 h prior to the accident flights. As a result, the impact of pilot fatigue cannot be assessed.

The authors of this paper are unaware of other challenges to the basis for the claims in the NTSB report [16] that it is not possible for oil fumes to either have contaminated the bleed air on these aircraft or to have played any role in any of these accidents.

Theirs is not the first report, however, to either overlook or downplay the flight safety implications of breathing oil or hydraulic fluid fumes. For example, one published case study investigated the findings of six documented fume event investigations and identified specific oversights and misconceptions about the potential for oil to contaminate the bleed air, as well as a tendency to dismiss the crew-reported symptoms as stress reactions [27]. Another investigation described an event during which pilots reported a blue haze shortly after reaching cruise altitude, prompting a precautionary landing [28]. The initial ground-based engine runs failed to identify any fault. Only additional (and non-standard) high-power engine runs identified the source of fumes—a fractured bearing seal in the compressor. This is important because high-power runs were not part of the fault-finding procedure endorsed by the aircraft manufacturer.

Another investigation described how both pilots reported fumes during approach and felt dizzy and nauseous, with irritated eyes and throat [29]. The pilots donned oxygen and requested priority landing clearance. The auxiliary power unit (APU) was not operating during the approach phase, so it was not investigated as a potential source of oil contamination. However, the aircraft manufacturer has published bulletins alerting airlines that, when the APU is in use, oil fumes can contaminate the downstream environmental control system and ducting, and fumes from that initial contamination can continue to manifest inflight, even when the APU is not in use [30]. Still, the APU was not checked, and the investigation was inconclusive; "no explanation" for either the fumes or the symptoms was found.

In 2020, the French Bureau of Enquiry and Analysis for Civil Aviation Safety (BEA) investigated a serious incident on a commercial flight during which the pilots reported a strong, acrid odor accompanied by irritant symptoms during taxi, shortly after the APU had been turned on [31]. During the climb out, both pilots reported dizziness, among other symptoms. They eventually donned oxygen masks and diverted to the nearest airport.

Although the details are consistent with breathing bleed-sourced oil fumes, maintenance inspections did not identify an obvious mechanical failure. As a result, the accident investigator concluded that the incident—including fumes, persistent symptoms, and a diversion—was most likely caused by the pilots inhaling "an excessive quantity of carbon monoxide." Failing to find a more plausible explanation, the accident investigators hypothesized that the source of the fumes may have been engine exhaust from a small business jet as it taxied about 80 m away from the incident aircraft in the presence of a "calm wind." However, the report added that it "cannot be excluded that the crews were intoxicated by another substance." This incident highlights the value of installing and operating sensors onboard, both to provide real-time information to the pilots and assist maintenance in subsequent troubleshooting.

Other than its investigation into these ten turboprop crashes in 1979–1981, the NTSB has not weighed in on the flight safety implications of pilots inhaling oil-contaminated bleed air inflight. This is contrary to its counterparts in Australia [32,33], Germany [4], Iceland [34], Ireland [35], New Zealand [36], Spain [5], Sweden [37], Switzerland [7], and the UK [3,6], for example. Each of those safety boards has investigated one or more commercial flights involving pilots whose inflight impairment compromised flight safety and has concluded that breathing contaminated bleed air either likely or definitively played a role. The NTSB does require airlines to report onboard fume/smoke events, but only if either the aircraft sustained structural damage or if specific health impacts were reported by one or more occupant (49 CFR § 830.2). However, oil fume events that meet the NTSB reporting criteria have not been investigated.

4.2. Bearing and Seal Failures in the TPE331 Engine

The description in [16] of the two seals in series contains some contradictions. According to the explanation, the carbon seal is necessary because "when the engine is shutdown, oil drains from the engine walls which increases the oil level above the shaft installation level of the compressor" [16] (p. 33). The labyrinth seal is necessary because the carbon seal is potentially "subject to wear and damage" [16] (p. 2). So, if the carbon seal is worn or damaged, then the oil will flow out of the reduction gearbox into the compressor and contaminate the cabin air when the engine is next started up. This situation was investigated in test 5 [16].

It is known that all seals leak in small quantities [38]. Pressure differentials assumed by the manufacturer may not be present in failure cases. Moreover, pressure differentials may not be sufficient during rapid thrust reduction or at idle thrust. In test 4, it was assumed only that one of the two seals in series (the carbon seal) would have failed. The labyrinth seal was left intact. Certainly, a mechanical failure that causes the carbon seal to fail may also cause the labyrinth seal to fail at the same time. For example, a failure of the main shaft compressor bearing could cause the main shaft to vibrate or rotate eccentrically which could severely damage (or even destroy) both seals.

In addition to crash number 1 (Table 5), an TPE331 compressor bearing failure which caused the engine to fail was documented by the Australian Transport Safety Bureau (ATSB) [39], although without either fatalities or reference to oil fumes. That report described the history of compressor bearing failures on the TPE331 engine which peaked in the early to mid-1980s. Garrett attributed the compressor bearing failures to propeller strikes and subsequently revised the engine maintenance manual, which—by the 1990s—reduced the number of failures. In the accident investigated by the ATSB, when the compressor bearing failed, the bearing cage fractured which caused the balls to come loose. Such loose components can collide with and cause damage to numerous internal rotating engine components, including the compressor seals.

4.3. Bleed Air Testing

Regarding the engine bleed air testing reported by the NTSB [16], the conditions in trials 1–4 did not represent the conditions of concern on the crashed aircraft because the

engine compressor carbon seal was intact and, in all but one case, the air was filtered for vapor and particulate. No measurements were collected during trial 5a. Regarding the relevance of conditions tested during trial 5b, on the one hand, the bleed air would have contained oil from the dirty engine start, but it is not clear if this is the same volume and pattern of oil as with a faulty engine compressor carbon seal inflight. Moreover, the bleed air had been passed through a glass wool filter for vapors and particulate, unlike on the crashed aircraft. Finally, it is not clear if the temperatures in the test stand compressor reflected inflight conditions.

It is important to carefully consider the question of the temperature in the engine compressor on these crashed aircraft. In its report, the NTSB referenced some certification data collected by a major engine manufacturer after injecting oil into a large turbofan engine. The tests showed that that carbon monoxide formation was detectable starting around 316 °C [16] (p. 7). The report also notes that TPE331 engine has a standard compressor discharge temperature of 360 °C [16] (p. 6) with a maximum temperature of 386 °C [16] (p. 25). The compressor temperature was high enough for carbon monoxide to be generated in the presence of oil, but the authors claim that the concentration of carbon monoxide would have been too low to cause impairment [16] (p. 2). The authors also rule out the presence of other oil decomposition products (such as acrolein) sufficient to irritate the mucous membranes by noting that "a number of participants sniffed the bleed air lines . . . [and] no one described an acrid or irritating quality"; [rather] "the consensus was that the odor was that of a warm oil, not a decomposed oil" [16] (p. 27).

In a companion study, CAMI researchers exposed test animals to Exxon 2380 oil for seven hours without, what the NTSB called, "any immediate or delayed behavioral change" [16] (p. 28). The CAMI report does describe an experiment with rats and chickens exposed to aerosolized (but unheated oil) in which the animals seemed unaffected [17] (p. 14). However, in the same study the CAMI researchers reported that, when the engine oil was heated, carbon monoxide started to form at 306 °C and when rats in one trial were exposed to oil fumes heated to 350 °C for 30 min, "it was obvious that the animals were approaching incapacitation" [17] (p. 8). Moreover, when the temperature was further increased, the animals "expired." Unlike the rats, the pilots on the crashed planes would have inhaled oil fumes in a reduced pressure environment with a corresponding reduction in the partial pressure of oxygen in the ambient air.

More recent sampling data has highlighted the presence and potential health impact of elevated levels of ultrafine particles in the bleed air supplied to the cabin and flight deck on commercial aircraft [40–44]. As noted above, the authors of the NTSB report assumed that "particulate matter would not form" [16] (p. 9), and so did not assess any associated toxicity.

4.4. Regulations

In the 1960s, a report from an aircraft manufacturer (Douglas Aircraft Corporation) describes the need to "show that the level of contamination required for olfactory warning is well below the generally accepted tolerance limits for the toxic materials produced" [15] (p. 3). In 1960, U.S. aircraft manufacturers would have been required to demonstrate to the U.S. Civil Aeronautics Board (which predated the FAA) that aircraft systems were designed to provide ventilation air "free from harmful or hazardous concentrations of gases or vapors", which included (but was not limited to) the carbon monoxide concentration not exceeding 50 ppm [45]. Presumably, this is what motivated Douglas Aircraft Corporation to propose testing to demonstrate that, "under all possible oil leakage rates," olfactory warnings would give pilots sufficient time to "permit effective crew countermeasures." [15] (p. 3). Essentially, tests needed to show that pilots would smell oil fumes before they would be impaired, proving that the presence of oil-based contaminants in bleed air was safe.

Since then, many studies and reports discuss the presence of airborne contaminants in cabin air and comment on whether the levels are "safe" or "acceptable" [40,46–48]. "Acceptability" has more commonly been framed in the context of comparing aircraft data

to published exposure limits for individual chemical constituents [16,40,49,50], although this approach is not without criticism [51,52].

The quest to define "safe" or "acceptable" concentrations of oil-based compounds is likely borne from the need for industry to comply with the regulation that the aircraft supply system be designed to supply air that is "free from harmful or hazardous concentrations of gases or vapors" (14 CFR § 25.831(b)). If something is acceptable—if it is not harmful—then the design meets the regulation. Interestingly, though, the FAA does not define "harmful or hazardous" beyond its limits for carbon monoxide (14 CFR § 25.831(b)(1)) and carbon dioxide (14 CFR § 25.831(b)(2)) and it had not done so in the early 1980s either. Applying published exposure limits for individual chemicals to complex mixtures [53] (Appendix 10) is problematic [54], especially in a reduced pressure and safety-sensitive environment [52]. This is in part because exposure limits do not exist for every constituent in these mixtures and the various constituents have a variety of toxicity endpoints. Moreover, the diversity of exposure limits published by different authorities for a single chemical illustrates the fallacy that a single number can define the boundary between what is and is not acceptable. In the case of the FAA, their limits for carbon monoxide and carbon monoxide are as high—or higher—than published chemical exposure limits for ground-based application. So, given this gap in the regulatory framework, in 1981, the NTSB and their industry colleagues defined "safety" for themselves—not in the context of certification regulations, but in the context of whether pilots could have been impaired.

The authors of the 1984 NTSB report acknowledged that carbon monoxide would be generated when oil was purposefully introduced into the compressor section of the TPE331 engine, but they noted that it should be "well below permissible limits in the bleed air" [16] (p. 2). However, the permissible exposure limit for carbon monoxide is not a useful benchmark for safety. An applied research study into the effects of exposure to carbon monoxide inflight concluded that "the maximum permissible concentration of carbon monoxide in pressurized passenger airplane cabins should be 0.01 mg/liter," which is equivalent to 8.7 ppm [55]. By comparison, the permissible aircraft design limit for carbon monoxide is 50 ppm (14 CFR § 25.831(b)(1)) which is, inexplicably, as high, or higher than ground-based limits. This, even though it is primarily applied in a reduced pressure environment (14 CFR § 25.841(a)) with a corresponding reduction in the partial pressure of oxygen available to occupants. Safety of flight depends on pilots' alertness and reaction time which can be compromised by exposure to asphyxiants, such as carbon monoxide [56]. Moreover, aircraft occupants have no means of egress once the doors are closed, such that an additional safety factor regarding exposure to carbon monoxide is warranted. Finally, carbon monoxide is only one element of a complex chemical mixture.

4.5. Exposure Control Measures

Just as the flight safety implications of breathing oil and hydraulic fluid fumes have been well documented, the need for control measures has also long been recognized. In 1966, an aircraft manufacturer reported that, in response to the evidence that contaminated bleed air could have caused some fatal crashes, the Navy required that crewmembers breathe 100% oxygen from takeoff to landing [15]. In 1955, an engineer with North American Aviation described the outcome of a two-year investigation into engineering solutions to prevent bleed air contamination, recommending either a separate compressor or a bleed air filter [57]. In response to one oil fume event during the descent phase of a commercial flight, the UK Air Accidents Investigation Board recommended that the FAA and EASA "consider requiring" a system to warn pilots about the presence of "smoke or oil mist in the air delivered from each air conditioning unit" [58]. Engineering and operational measures continue to be called for, including bleed air filtration, sensors to provide early warning of airborne contaminants, improved maintenance procedures, more targeted troubleshooting procedures, relocating the air inlet for the auxiliary power unit, and airline worker training and education [59,60].

5. Conclusions

Between 1979 and 1981, NTSB investigators suggested that inhaling oil fumes inflight may have been a causal factor in "several" fatal crashes of turboprop aircraft. In response, the agency partnered with the very companies that had a commercial interest in the outcome of the investigation. Aside from noting the potential for some people to develop "extreme chemical sensitivity" [16] (p. 28) to chemicals in oil fumes, the NTSB and their industry partners soundly dismissed the hypothesis that oil fumes may have impaired some of the pilots on the crashed planes, affirming that it was "completely without validity" [16] (p. 3). However, their conclusions are not supported by the evidence for three key reasons.

First, it was not—and is not—possible to draw any definitive conclusions regarding the cause of these crashes because real-time bleed air testing and suitable post-mortem blood analyses were not available. However, the accident reports for four of the fatal crashes on these turboprop aircraft include details consistent with (and suggestive of) the pilots being impaired by oil fumes (Table 5). Moreover, this is consistent with similar concerns and reports of pilot impairment documented since the 1930s, such that "pilot error" and "undetermined" are insufficient explanations. Without air supply monitoring equipment to provide real-time warning, and without options for a blood test to investigate inhalation of oil fumes, aircraft crashes that are attributable to bleed air contaminants will not be recognized as such.

Second, none of the tests of ground-based bleed air measurements of a subset of oil-based contaminants generated in the engine type that had been on the crashed aircraft reproduced the types of inflight conditions that the accident investigators had flagged as potentially unsafe (Tables 3 and 5). Specifically, the engine test stand conditions did not assess the impact of oil seeping through a cracked or otherwise damaged compressor seal on the quality of unfiltered bleed air downstream. As a result, the bleed air testing results are not relevant to the question of whether oil fumes could have impaired the pilots inflight. As such, the argument that they somehow discount the potential for impairment is invalid.

Finally, to interpret the bleed air data they collected, the authors of the report used published exposure limits as a benchmark for whether the concentration of gaseous compounds in oil fumes would have been sufficient to cause pilot impairment. However, published exposure limits are not appropriate for assessing the risks associated with inhaling a complex mixture of compounds in an enclosed and reduced pressure environment.

The significant concerns raised by these crashes and the history of pilot impairment associated with breathing oil fumes all support more stringent design, operation, and reporting regulations to protect safety of flight.

6. Recommendations

- For current aircraft that are equipped with bleed air systems, engineering control measures such as sensors and filters should be mandated to prevent inflight exposure to fumes and, thus, improve flight safety. For new aircraft types, non-bleed air supply systems should be standard.
- Given the flight safety implications, all crewmembers should be trained to recognize and respond to the presence of bleed air contaminants [61].
- The NTSB should reopen the 1984 report and update the conclusions based on what was known then about oil fumes and flight safety, and considering the data and reports published since then. The NTSB should also issue recommendations to the FAA on necessary actions to minimize the flight safety impacts of exposure to oil fumes.
- Until suitably protective measures are implemented fleet-wide, the NTSB should consider pilot impairment from bleed-sourced fumes as a potential casual factor in future aircraft accident investigations. This is particularly important when an accident includes either relevant maintenance history or a pilot's failure to communicate, for example.
- If only to avoid the appearance of bias, future investigations should be independent of all commercial interests. Even though it is not unusual for the NTSB to include the FAA and manufacturers in accident investigations, both the poorly conceived design

of the air sampling trials and the sweeping conclusions, suggest that commercial conflicts influenced this project.

Author Contributions: Conceptualization and methodology, J.A. and D.S.; investigation, J.A.; writing—original draft preparation, J.A.; writing—review and editing, J.A. and D.S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript.

CAMI	United States Civil Aeromedical Institute
CFR	United States Code of Federal Regulations
CS	Certification Specification (issued by EASA)
EASA	European Union Aviation Safety Agency
FAA	United States Federal Aviation Administration (issued by the FAA)
FAR	United States Federal Aviation Regulation
lb/hr	pounds per hour
NTSB	United States National Transportation Safety Board
psia	pound-force per square inch absolute (relative to zero or absolute vacuum)
psig	pound-force per square inch gauge (relative to atmospheric pressure; at sea level 14.7psi)
rpm	revolution per minute
TPE	turboprop engine

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Oil Fumes, Flight Safety, and the NTSB

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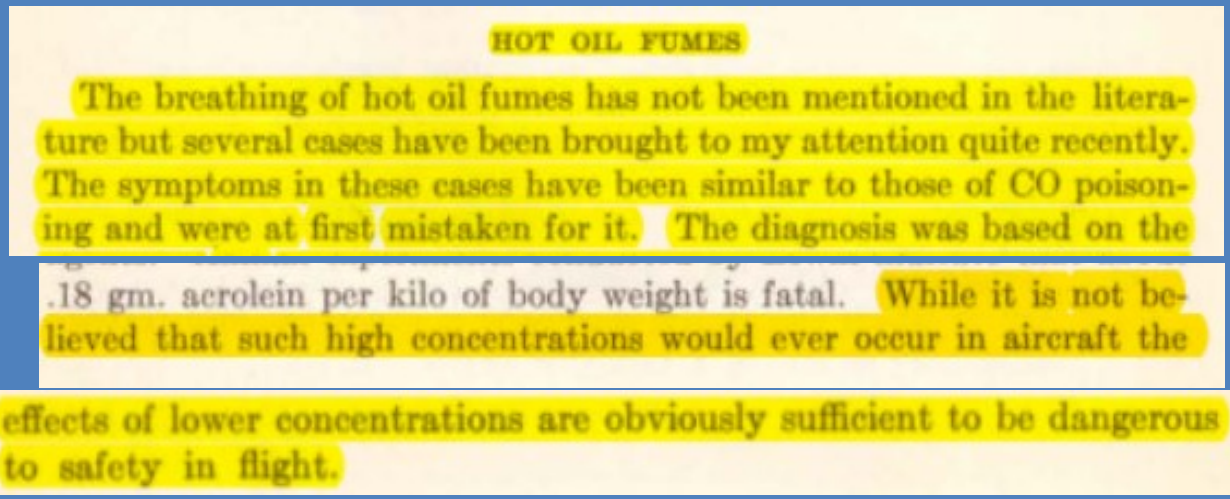
Aircraft Cabin Air Conference
March 16, 2021

Overview

1. Who says oil fumes can compromise flight safety?
2. NSTB investigation into 10 crashes (including highlights of accident reports - 1978, 1979)
3. More recent examples of compromised flight safety
4. Recommendations

Compromised flight safety example- 1939

Av. medicine textbook, written by physician in US Army, Aeromedical Research Lab

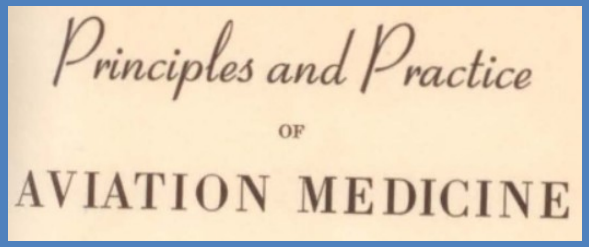


HOT OIL FUMES

The breathing of hot oil fumes has not been mentioned in the literature but several cases have been brought to my attention quite recently. The symptoms in these cases have been similar to those of CO poisoning and were at first mistaken for it. The diagnosis was based on the

.18 gm. acrolein per kilo of body weight is fatal. While it is not believed that such high concentrations would ever occur in aircraft the

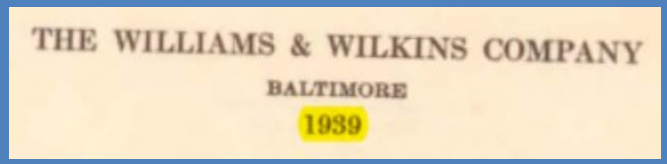
effects of lower concentrations are obviously sufficient to be dangerous to safety in flight.



Principles and Practice

OF

AVIATION MEDICINE



THE WILLIAMS & WILKINS COMPANY

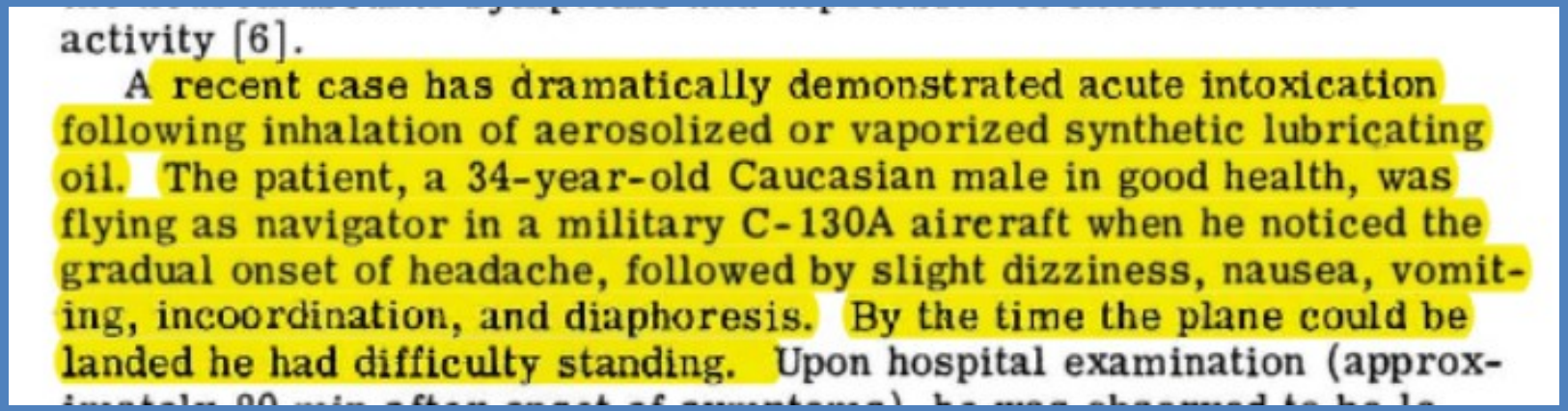
BALTIMORE

1939

Armstrong, HG (1939) "Noxious fluids and gases in aviation: hot oil fumes" (pp. 178-180), In: Principles and Practice of Aviation Medicine, Aero Medical Research Laboratory, United States Army, Published by The Williams & Wilkins Company, Baltimore, USA

Compromised flight safety example- 1977

Peer-reviewed paper authored by pulmonary/toxicology specialists



activity [6].

A recent case has dramatically demonstrated acute intoxication following inhalation of aerosolized or vaporized synthetic lubricating oil. The patient, a 34-year-old Caucasian male in good health, was flying as navigator in a military C-130A aircraft when he noticed the gradual onset of headache, followed by slight dizziness, nausea, vomiting, incoordination, and diaphoresis. By the time the plane could be landed he had difficulty standing. Upon hospital examination (approx-

Montgomery, MR; Wier, GT; Zieve, FJ; et al (1977) "Human intoxication following inhalation exposure to synthetic jet lubricating oil," Clin. Toxicol., 11(4): 423-426

Compromised flight safety example- 2004

US Federal Aviation Administration Airworthiness Directive 2004-12-05 (BaE146 aircraft)

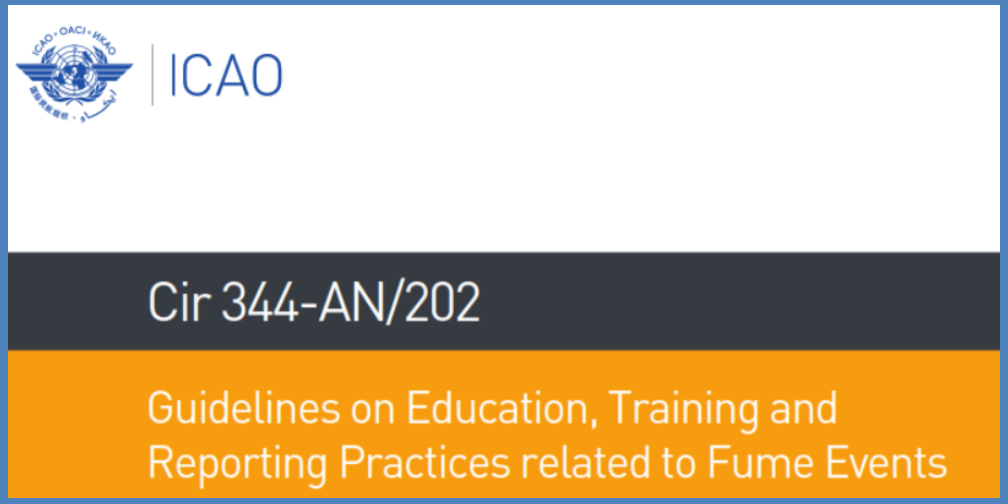
ACTION: Final rule.

SUMMARY: This amendment adopts a new airworthiness directive (AD), applicable to all BAE Systems (Operations) Limited Model BAe 146 series airplanes, that requires repetitive detailed inspections of the inside of each air conditioning sound-attenuating duct, and corrective actions as necessary. This action is necessary to prevent impairment of the operational skills and abilities of the flightcrew caused by the inhalation of agents released from oil or oil breakdown products, which could result in reduced controllability of the airplane. This action is intended to address the identified unsafe condition.

FAA (2004) "Airworthiness Directive 2004-12-05: BAE Systems (Operations) Limited Model BAe 146 Series Airplanes" Docket No. 2003-NR-94-AD, Federal Aviation Administration, Washington, DC

Compromised flight safety example- 2015
International Civil Aviation Organization

1.1.2 Of all of these potential contaminants in the cabin and flight deck, particular concerns have been raised regarding the negative impact on flight safety when crew members are exposed to oil or hydraulic fluid fumes or smoke, and experience acute symptoms in flight. Due to the potential flight safety implications, it is beneficial to provide guidance and instructional material to enable crew members to promptly recognize and respond to suspected air supply system-sourced fumes, as well as to enable aircraft maintenance technicians (AMT) to identify the source of the contaminants and to correct the issue.



ICAO (2015) “Guidelines on education, training, and reporting practices related to fume events,” Circular 344-AN/202, International Civil Aviation Organization, Montreal, Canada

More examples of reports that cite compromised flight safety: 1955-2020

- **AAIB (2020)** Bulletin no. 9/2020, Airbus A320-232, G-EUYB, UK Air Accidents Investigation Branch, UK Department for Transport, Aldershot, England.
- **IFALPA (2018)** "Cabin fumes," Human Performance Briefing Leaflet 18HUPBL03 and Position Paper 18POS24, International Federation of Airline Pilots' Associations, Montreal, Canada.
- **ASRS (2017)** "Aviation Safety Reporting System incident ACN: 1437845" Aviation Safety Reporting System, National Aeronautics and Space Administration, Moffett Field, California
- **AAIU (2016)** "Report no. 2016-013: Serious incident Boeing 737-8AS, EI-EFB near Stansted, United Kingdom, 18 Sept. 2014." Air Accident Investigation Unit of Ireland, Dublin, Ireland
- **CIAIAC (2014)** "Interim Statement A-008/2013: Accident occurred to aircraft Boeing B-757-300, registration D-ABOC, operated by Condor Flugdienst GmbH, at Gran Canaria airport on 22 March 2013," Civil Aviation Accident and Incident Investigation Commission, Madrid, Spain
- **AAIB (2013)** Bulletin no. 3/2013, Boeing 757-28A, G-FCLA (EW/G2012/10/09), UK Air Accidents Investigation Branch, UK Department for Transport, Aldershot, England
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- Rayman, RB and McNaughton, GB (1983) "Smoke/fumes in the cockpit" Aviat. Space Environ. Med., 54(8): 738-740
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- Crane, CR; Sanders, DC; Endecott, BR; et al (1983) "Inhalation toxicology: III. Evaluation of thermal degradation of products from aircraft and automobile engine oils, aircraft hydraulic fluid, and mineral oil," Aviation Medicine Report FAA AM-83-12, Civil Aeromedical Institute, US Federal Aviation Administration, Oklahoma City, Oklahoma
- Treon, JF; Cappel, JW; Cleveland, FP; et al. (1955) "The toxicity of the products formed by the thermal decomposition of certain organic substances." Am Ind Hyg Assoc Quarterly, 16(3): 187-195

Overview

1. Who says oil fumes can compromise flight safety?
2. NSTB investigation into 10 crashes (including highlights of accident reports - 1979, 1980)
3. More recent examples of compromised flight safety
4. Recommendations

US National Transportation Safety Board (NTSB)

- The NTSB is a US government agency overseeing safety in transportation for all modes (airlines, railways, trucking, etc.).
- It is responsible for investigating transportation accidents, conducting transportation safety studies, issuing safety recommendations, aiding victims' families after disasters, and promoting transportation safety.
- It was established as an independent agency because it may have to investigate the role that government agency (e.g., FAA) played in an accident, for example. So, being independent gives NTSB more freedom to be honest and criticize the FAA (and others), as needed, in the interest of safety.





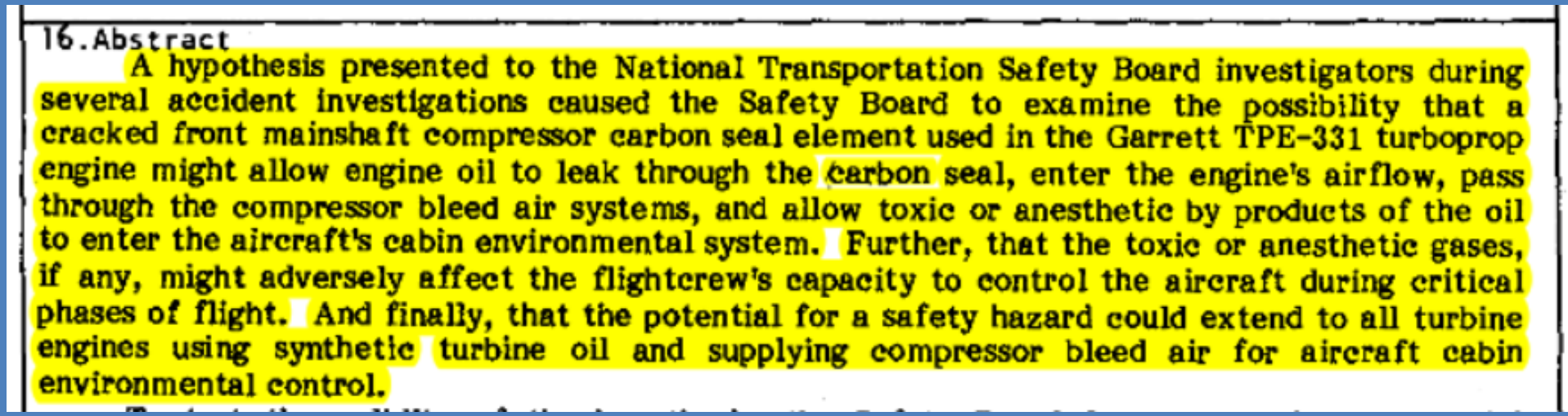
SPECIAL INVESTIGATION REPORT

AN EVALUATION OF THE GARRETT TPE 331 ENGINE'S POTENTIAL FOR TURBINE OIL BY-PRODUCT CONTAMINATION OF AN AIRCRAFT CABIN ENVIRONMENTAL SYSTEM

NTSB/SIR-84/01

NTSB reporting/investigation rules relevant to fume events

- In 1981, NTSB initiated an investigation into 10 turboprop crashes (1979-81) in response to a hypothesis that the pilots had been impaired by oil fumes – all aircraft had the same engine lubricated with the same type of oil.



16. Abstract

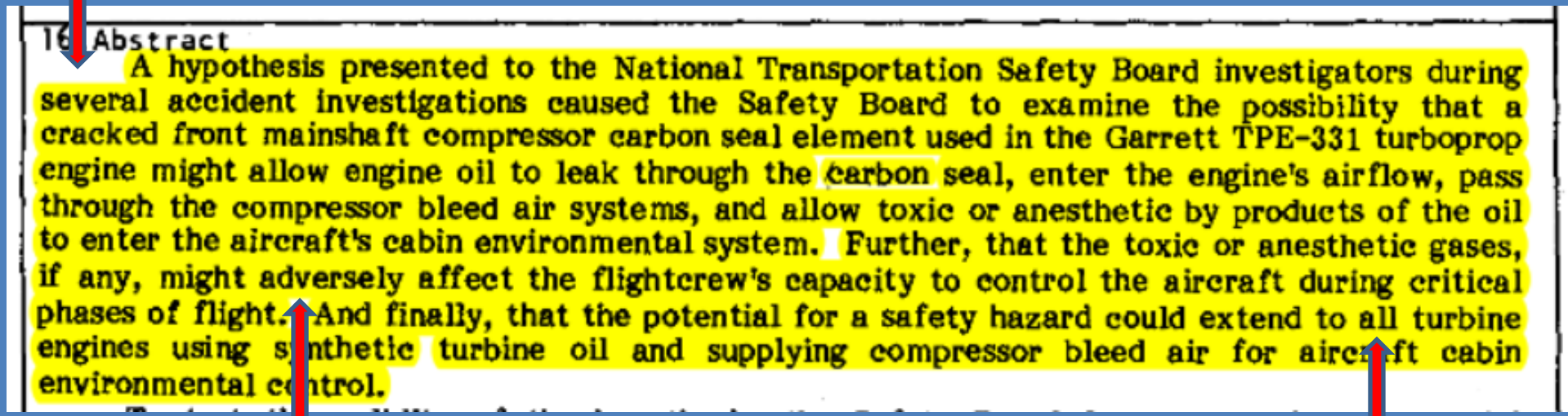
A hypothesis presented to the National Transportation Safety Board investigators during several accident investigations caused the Safety Board to examine the possibility that a cracked front mainshaft compressor carbon seal element used in the Garrett TPE-331 turboprop engine might allow engine oil to leak through the carbon seal, enter the engine's airflow, pass through the compressor bleed air systems, and allow toxic or anesthetic by products of the oil to enter the aircraft's cabin environmental system. Further, that the toxic or anesthetic gases, if any, might adversely affect the flightcrew's capacity to control the aircraft during critical phases of flight. And finally, that the potential for a safety hazard could extend to all turbine engines using synthetic turbine oil and supplying compressor bleed air for aircraft cabin environmental control.

The most important words:

"several accident investigations"

"adversely affect flight crew"

"could extend to all turbine engines"

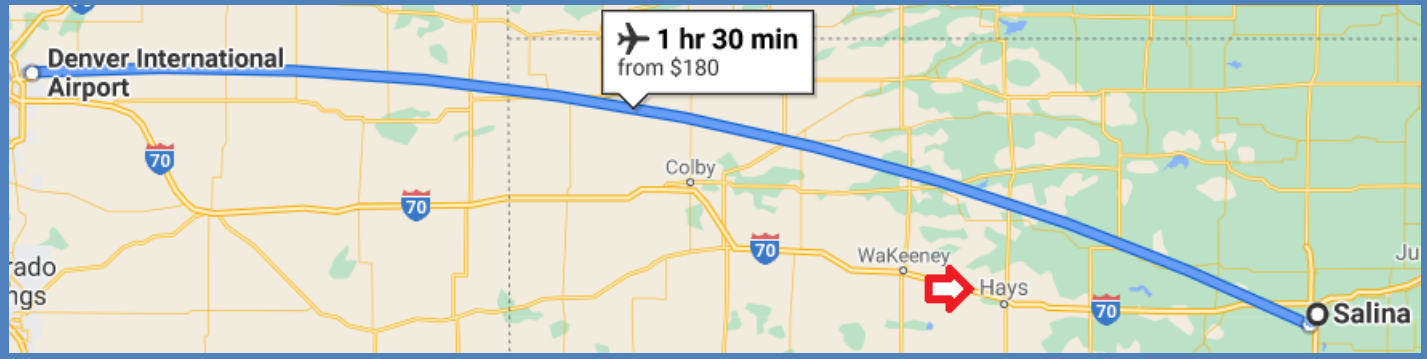


16 Abstract

A hypothesis presented to the National Transportation Safety Board investigators during several accident investigations caused the Safety Board to examine the possibility that a cracked front mainshaft compressor carbon seal element used in the Garrett TPE-331 turboprop engine might allow engine oil to leak through the carbon seal, enter the engine's airflow, pass through the compressor bleed air systems, and allow toxic or anesthetic by products of the oil to enter the aircraft's cabin environmental system. Further, that the toxic or anesthetic gases, if any, might adversely affect the flightcrew's capacity to control the aircraft during critical phases of flight. And finally, that the potential for a safety hazard could extend to all turbine engines using synthetic turbine oil and supplying compressor bleed air for aircraft cabin environmental control.

Example: Flight from Salina, KS – Denver, CO on Aug. 3, 1979 (N208MA)

- Thomas Murfin: 34 y.o. pilot with 2,200 hours of flight time; dry weather



Not a factor.

(15) BRIEF CIRCUMSTANCES: *(Continue on separate sheet)*

The flight was enroute from Salina, Kansas, to Denver, Colorado. At approximately 2100 c.d.t. when the flight was a short distance northwest of Hays, Kansas, the pilot reported an indication of reduced oil pressure on the right engine. A few minutes later the pilot reported the right engine oil pressure had gone to zero and that the right engine had been shut down and the propeller feathered. The pilot also reported smoke and fumes in the cabin which cleared when he selected cabin ram air.

Aircraft crashed in Hays, KS

- Few minutes later, oil pressure was at zero; pilot shut down R engine and reported fumes and smoke onboard (cleared with ram air).

0201:06 N2084A Eight Mike Alpha were going to have to shut down we have shut down the right engine we've got a low oil pressure and some smoke in the cockpit.

- Pilot stopped communicating with ATC.
- Plane crashed into a field near the airport in Hays, KS.

(11) PASSENGERS: *(Name & Injuries)*

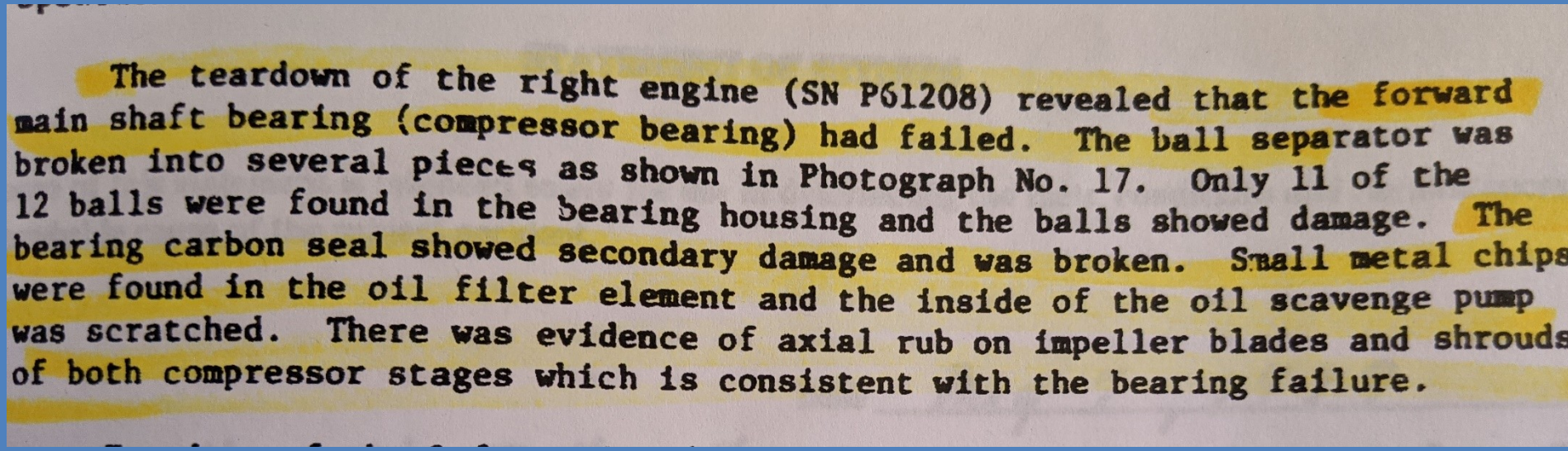
Joan Murfin - Fatal

Mathew, Mark, Michael, & Elizabeth

Murfin and Gregg Levin (all fatal)

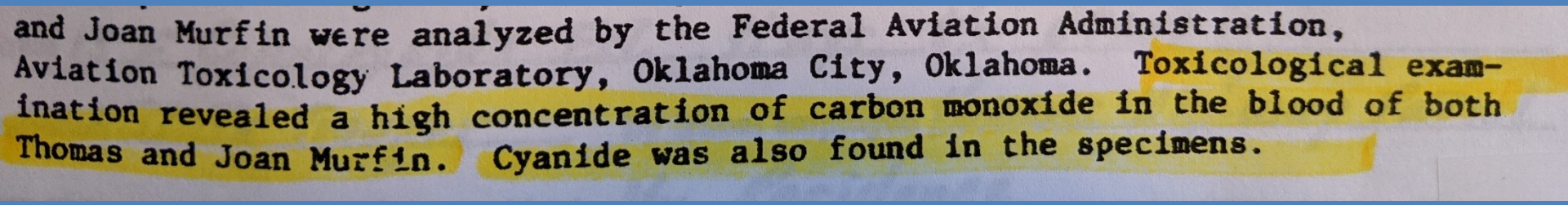
Mx investigation & post-mortem

- The compressor bearing in engine had failed.

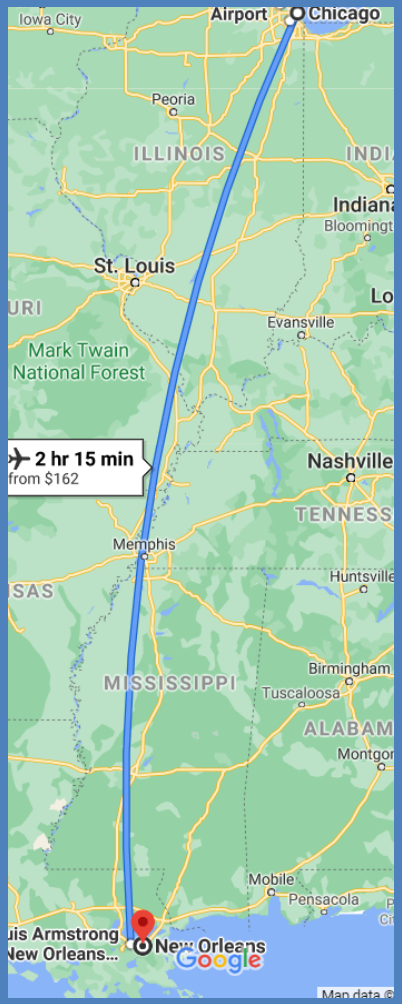


The teardown of the right engine (SN P61208) revealed that the forward main shaft bearing (compressor bearing) had failed. The ball separator was broken into several pieces as shown in Photograph No. 17. Only 11 of the 12 balls were found in the bearing housing and the balls showed damage. The bearing carbon seal showed secondary damage and was broken. Small metal chips were found in the oil filter element and the inside of the oil scavenge pump was scratched. There was evidence of axial rub on impeller blades and shrouds of both compressor stages which is consistent with the bearing failure.

- Post-mortem found carbon monoxide in blood. Potential sources include oil fumes, engine fire, explosion upon crash landing...



and Joan Murfin were analyzed by the Federal Aviation Administration, Aviation Toxicology Laboratory, Oklahoma City, Oklahoma. Toxicological examination revealed a high concentration of carbon monoxide in the blood of both Thomas and Joan Murfin. Cyanide was also found in the specimens.



Example 2: Flight from Chicago–New Orleans on Feb. 23, 1980 (N962MA)

- M. James: 61 y.o. pilot with 10,000 hours of flight time; dry weather; carrying six passengers
- On approach, pilot stopped responding to ATC.

was on the approach. He was then instructed to report passing the Alger intersection and acknowledged. He was then given the Lakefront weather (which was well below minimum for the approach). He did not acknowledge the weather transmission and did not report the Alger intersection. Shortly afterward his position was located by radar as being two miles north of the airport. The Tower then issued instructions, "check gear down - cleared to land." This transmission also was not acknowledged. Further, he failed to acknowledge a weather transmission issued by the New Orleans Approach Control prior to being vectored for the Lakefront approach

Maintenance investigation

- Aircraft had history of air supply system-sourced smoke/fumes.

of this report.

During the initial phase of the accident investigation it was reported by various persons that the aircraft had a history of smoke, fumes, and carbon monoxide collecting inside the cockpit and cabin area. Note: Investi-

- Carbon seal in L engine compressor had recently been replaced "to correct the discrepancy of smoke/fumes…" in the mx history.

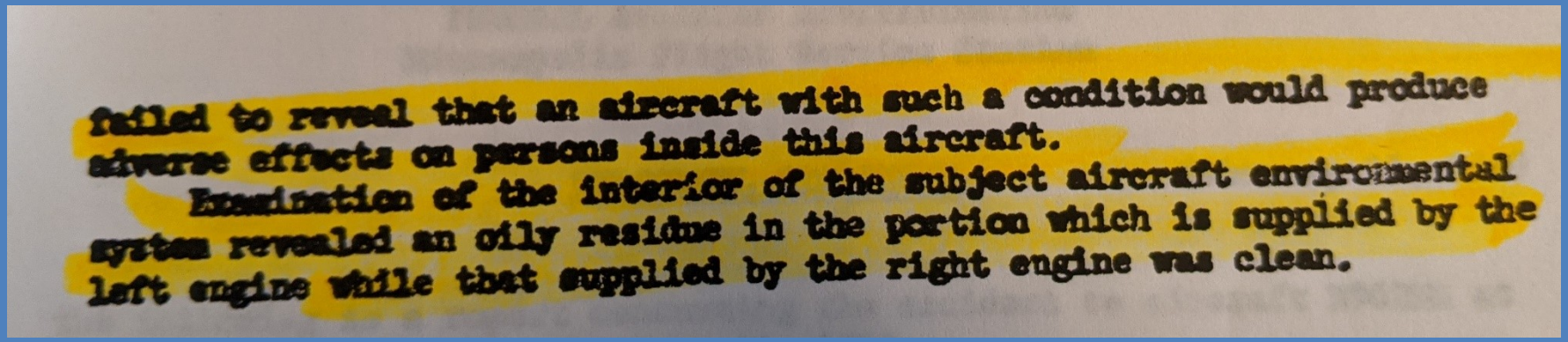
gation by the undersigned failed to reveal evidence that actual carbon monoxide concentrations were ever present in the aircraft.

The aircraft maintenance log revealed a carbon seal in the left engine compressor section had recently been replaced in order to correct the discrepancy of smoke and fumes inside the aircraft. Examination of the seal at that time revealed it was cracked. During engine disassembly after the accident it was noted that this same carbon seal was again cracked. However, it was the general consensus of all persons present that this crack most probably occurred at water impact.

Investigation revealed that if the referenced carbon seal becomes cracked engine oil can leak past it and into the compressor section. From this area it can be transferred with bleed air through the environmental system and into the cockpit and cabin area. However, extensive investigation has

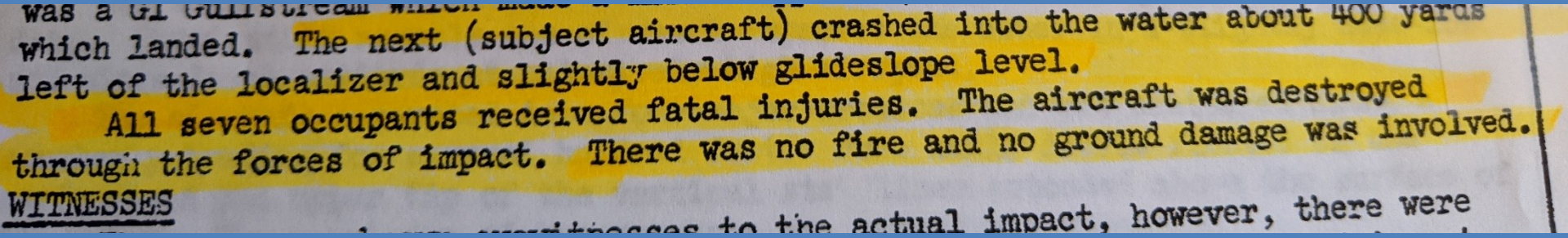
Evidence of oil in bleed air

- “Extensive investigation failed to reveal that an aircraft with such a condition would produce adverse effects on persons inside this aircraft.”


failed to reveal that an aircraft with such a condition would produce adverse effects on persons inside this aircraft.

Examination of the interior of the subject aircraft environmental system revealed an oily residue in the portion which is supplied by the left engine while that supplied by the right engine was clean.

- “Oily residue” in ECS downstream of left engine

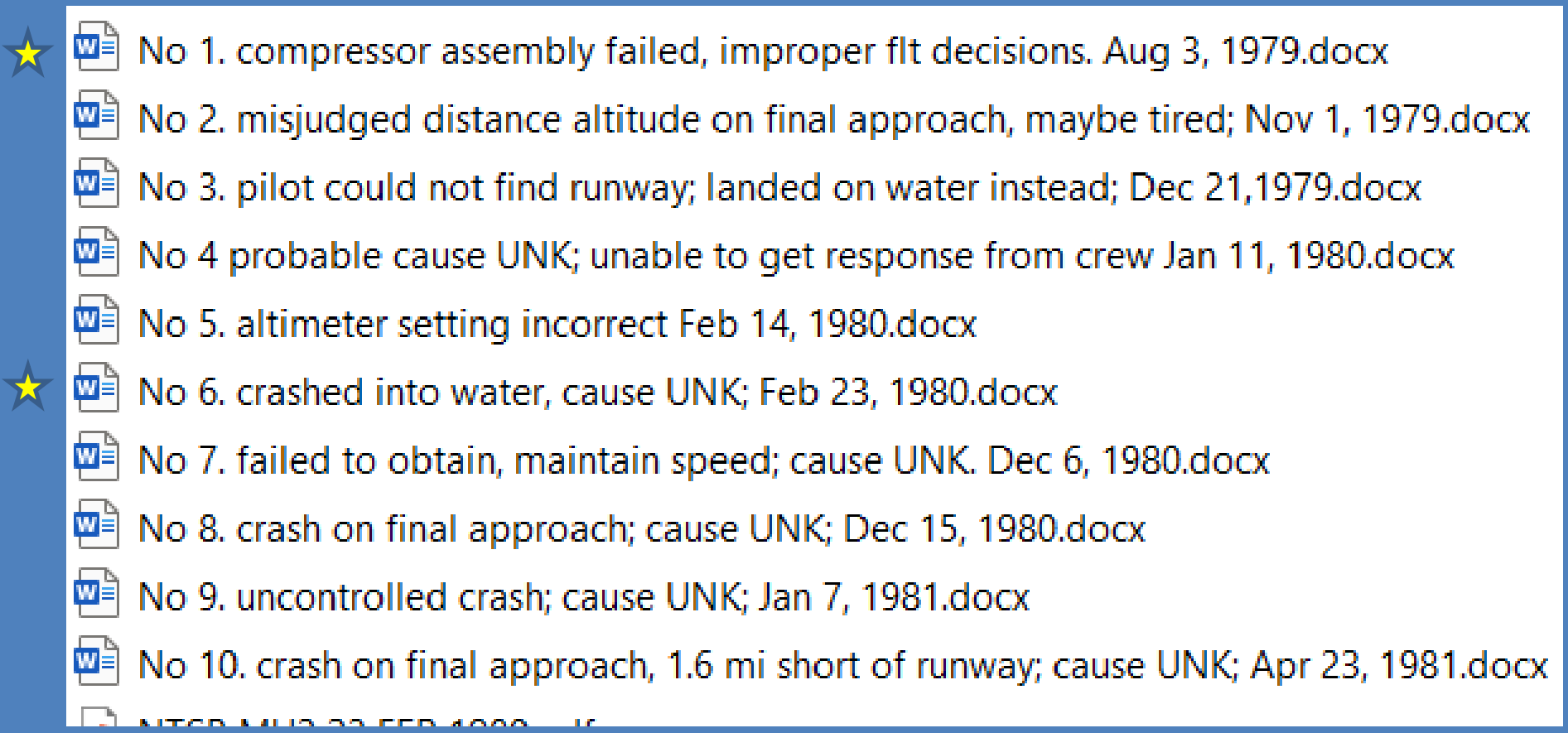

was a GI Gulfstream which made a [illegible] which landed. The next (subject aircraft) crashed into the water about 400 yards left of the localizer and slightly below glideslope level.

All seven occupants received fatal injuries. The aircraft was destroyed through the forces of impact. There was no fire and no ground damage was involved.

WITNESSES

[illegible] witnesses to the actual impact, however, there were

Probable causes of the 10 crashes: “undetermined”, “unknown”, “miscellaneous”, etc.



NTSB investigation – the plan

- During “several accident investigations” a hypothesis was presented to the NTSB…
- Step 1: NTSB set up a “Special Investigative Committee” – members included FAA, EPA, Garrett (manufacturer of engine on all of the crashed planes) and Exxon (manufacturer of oil lubricating engines on all of the crashed planes) to “aid the safety board in investigating the hypothesis”. (Not unusual, but the optics are bad…)
- They made a plan to test oil-based contaminants in bleed air supplied by the Garrett TPE 331 engine.

NTSB investigation: the measurements

- In July 1981, they ran 12 trials (10-15 minutes each) and measured various contaminants in the bleed air supplied by one of two Garrett TPE 331 engines lubricated with Exxon 2380 oil (Table IV). One of the engines had an intact carbon seal on the main shaft, one had a missing carbon seal (worst-case failure).

- In 11 of the 12 trials, they measured bleed air supplied by the engine with intact seal. Further, the bleed air was passed through a glass fiber filter before the sampling port (to prevent contamination of downstream sampling equipment… so measured gases). Added oil to bleed air in 6 of the 11 trials, all of which were filtered. Tests didn't reflect conditions of concern on the crashed aircraft.

- In one of the 12 trials, they measured bleed air supplied by engine with missing seal AND no filter AND oil contamination. But the oil was only heated to 160°F for 15 minutes. Actual compressor temp. would have been 300-600°F. Test conditions didn't reflect aircraft conditions.

NTSB investigation: the conclusions

1. "…the quality of the bleed air from the TPE-331 engine is not measurably different from the quality of ambient air" (even without a front mainshaft compressor carbon seal)

2. "No toxic compounds of significant amounts were found in the bleed air during any of the engine tests."

3. "No evidence that toxic oil contamination could occur…"

As a result of the ad hoc Committee's investigative findings, it is concluded that the hypothesis concerning subtle pilot incapacitation due to engine oil contamination of the bleed-air supply from the TPE 331 engine entering the cabin aircraft's environment is completely without validity.

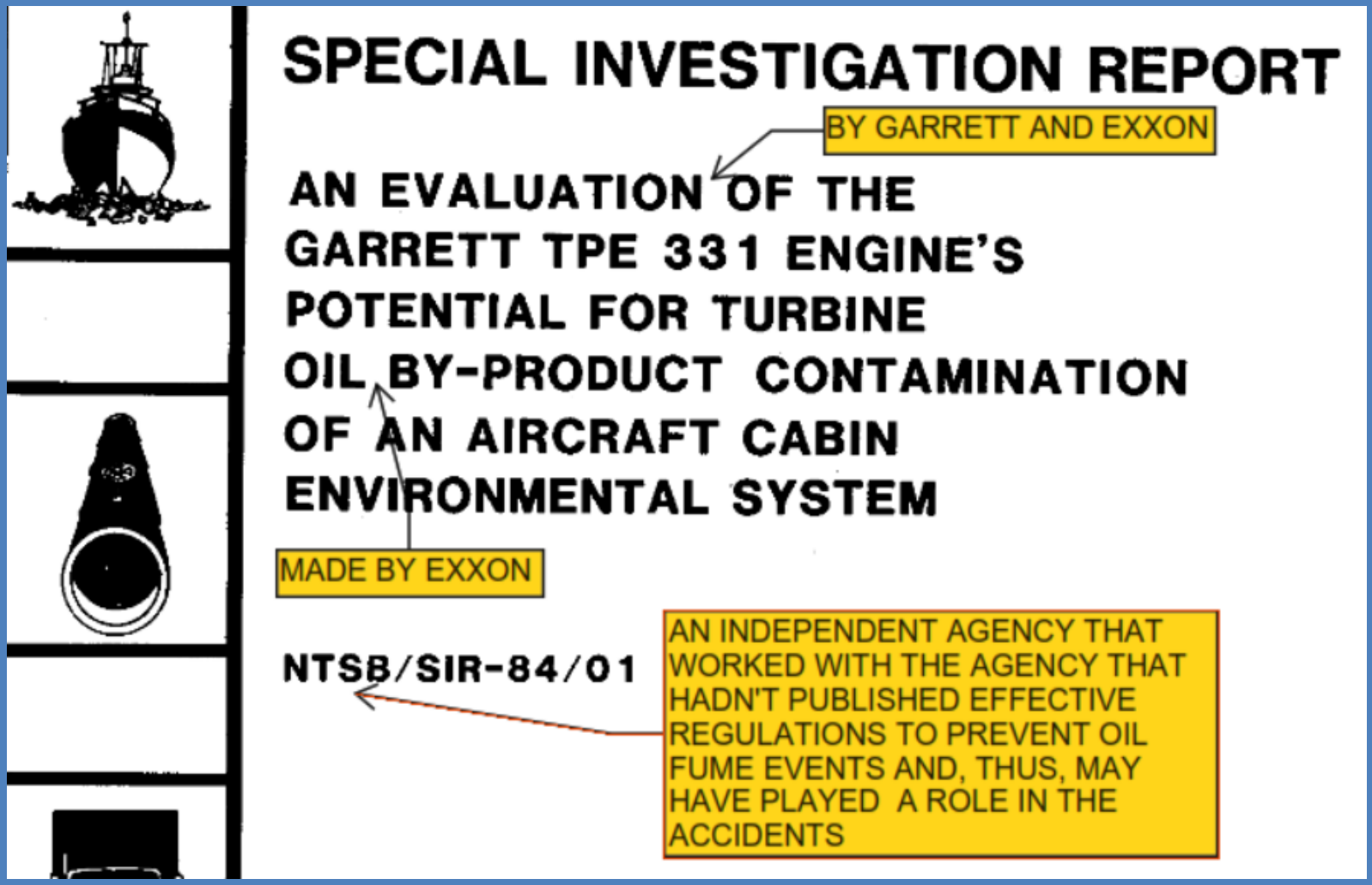
Outcome of accident investigations

- In the report abstract, the NTSB took its conclusions one step further. Right after acknowledging the "technical expertise" of Garrett, Exxon, and the FAA for formulating the tests and interpreting the results, they said that not only did oil fumes not incapacitate the pilots of those 10 aircraft -- contamination of the compressor air "is not possible".

included the technical expertise for formulating the tests and the analysis of the test results. As as result of the investigation, the Safety Board has concluded that contamination of compressor bleed air by the ingestion of engine oil is not possible.

Except that it is possible…

- **AAIB (2020)** Bulletin no. 9/2020, Airbus A320-232, G-EUYB, UK Air Accidents Investigation Branch, UK Department for Transport, Aldershot, England.
- **IFALPA (2018)** "Cabin fumes," Human Performance Briefing Leaflet 18HUPBL03 and Position Paper 18POS24, International Federation of Airline Pilots' Associations, Montreal, Canada.
- **ASRS (2017)** "Aviation Safety Reporting System incident ACN: 1437845" Aviation Safety Reporting System, National Aeronautics and Space Administration, Moffett Field, California
- **AAIU (2016)** "Report no. 2016-013: Serious incident Boeing 737-8AS, EI-EFB near Stansted, United Kingdom, 18 Sept. 2014." Air Accident Investigation Unit of Ireland, Dublin, Ireland
- **CIAIAC (2014)** "Interim Statement A-008/2013: Accident occurred to aircraft Boeing B-757-300, registration D-ABOC, operated by Condor Flugdienst GmbH, at Gran Canaria airport on 22 March 2013," Civil Aviation Accident and Incident Investigation Commission, Madrid, Spain
- **AAIB (2013)** Bulletin no. 3/2013, Boeing 757-28A, G-FCLA (EW/G2012/10/09), UK Air Accidents Investigation Branch, UK Department for Transport, Aldershot, England
- **BFU (2012)** "Bulletin: Accidents and incidents during operation of civilian aircraft, November 2011" German Federal Bureau of Aviation Accident Investigation, Braunschweig, Germany
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- **RNF (2009)** "Final report: Aircraft serious incident – Smoke in flight deck and cabin, engine shut-down and emergency landing" Icelandic Aircraft Accident Investigation Board (Rannsóknarnefnd flugslysa), Reykjavik, Iceland
- **CAA (2008)** "Flight Operations Department Communications (FODCOM) 17/2008" UK Civil Aviation Authority, Safety Regulation Group, Aviation House, Gatwick, West Sussex, England
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- Treon, JF; Cappel, JW; Cleveland, FP; et al. (1955) "The toxicity of the products formed by the thermal decomposition of certain organic substances." Am Ind Hyg Assoc Quarterly, 16(3): 187-195



Even though it is not unusual for the NTSB to include the FAA and manufacturers in accident investigations, both the poorly-conceived design of the air sampling trials and the sweeping conclusions, suggest that commercial conflicts controlled this project.

Overview

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2. NSTB investigation into 10 crashes (including highlights of accident reports - 1978, 1979)
3. More recent examples of compromised flight safety (briefly)
4. Recommendations

Examples of more recent accidents caused by fumes but not investigated:



- But that was the 1980s! We got a lot of things wrong! Surely, things have changed?
- AFA filed requests with NTSB to investigate fume events that qualified as accidents (per 49CFR830.2) in Jan. 2010, Oct. 2018, and July 2019.
- The airlines didn't report these events to the NTSB, even though they were required to do so. (AFA submitted FOIA requests for all relevant records, but was told that there were no records.)
- AFA requests for investigations were unanswered.

Even though the solutions have been recognized for decades…

ELIMINATION OF ENGINE BLEED AIR CONTAMINATION

Air bled from the compressors of some high compression ratio turbojet engines is contaminated because of internal engine oil leakage into the compressor air. External leakage of oil or other fluids wherein such fluids can leak into the engine air inlet can also cause contamination. There are two positive methods of elimination: (1) a catalytic filter which oxidizes the contaminants to carbon dioxide and water; (2) a separate cabin compressor that compresses free stream ram air for cabin air conditioning and pressurization. The method of extracting air from a location in the engine where the compressor air is

For presentation at the
SAE GOLDEN ANNIVERSARY AERONAUTIC MEETING
Hotel Statler, Los Angeles, Calif.
October 11-15, 1955

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Recommendations

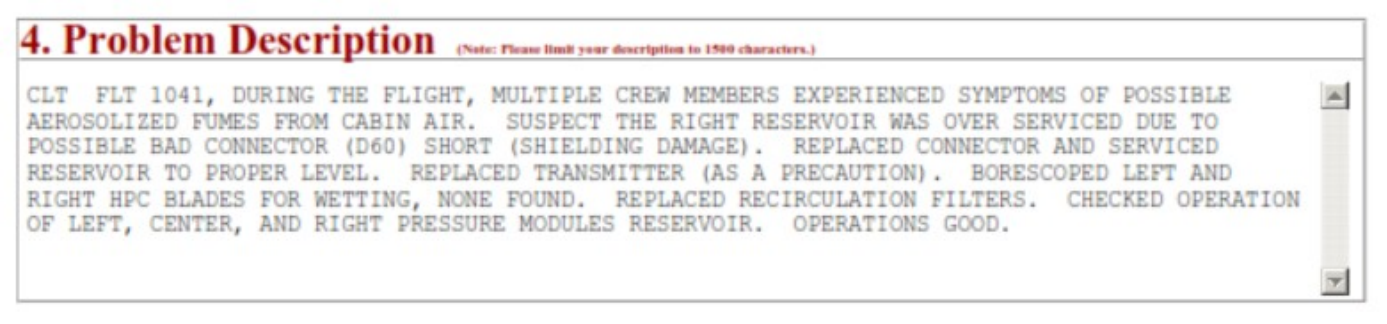
1. Congress increase NTSB funding to enable them to hire more staff to investigate more accidents, including those caused by fumes – not "just" the big disasters.

2. NTSB reopen the 1984 report and review/update the conclusions based on what was known about oil fumes/flight safety then, and also considering the data and reports published since then.

3. NTSB issue recommendations to the FAA on necessary actions to minimize the flight safety impacts of exposure to oil fumes.

Example of compromised flight safety on a commercial flight: Jan. 16, 2010

- On Jan. 16, 2010, Captain David Hill and First Officer Mick Fowler were impaired during the descent phase of USAirways flight 1041 because they were breathing oil fumes. They were taken off the aircraft on stretchers and transported to hospital along with the impaired cabin crew and eight sick passengers.



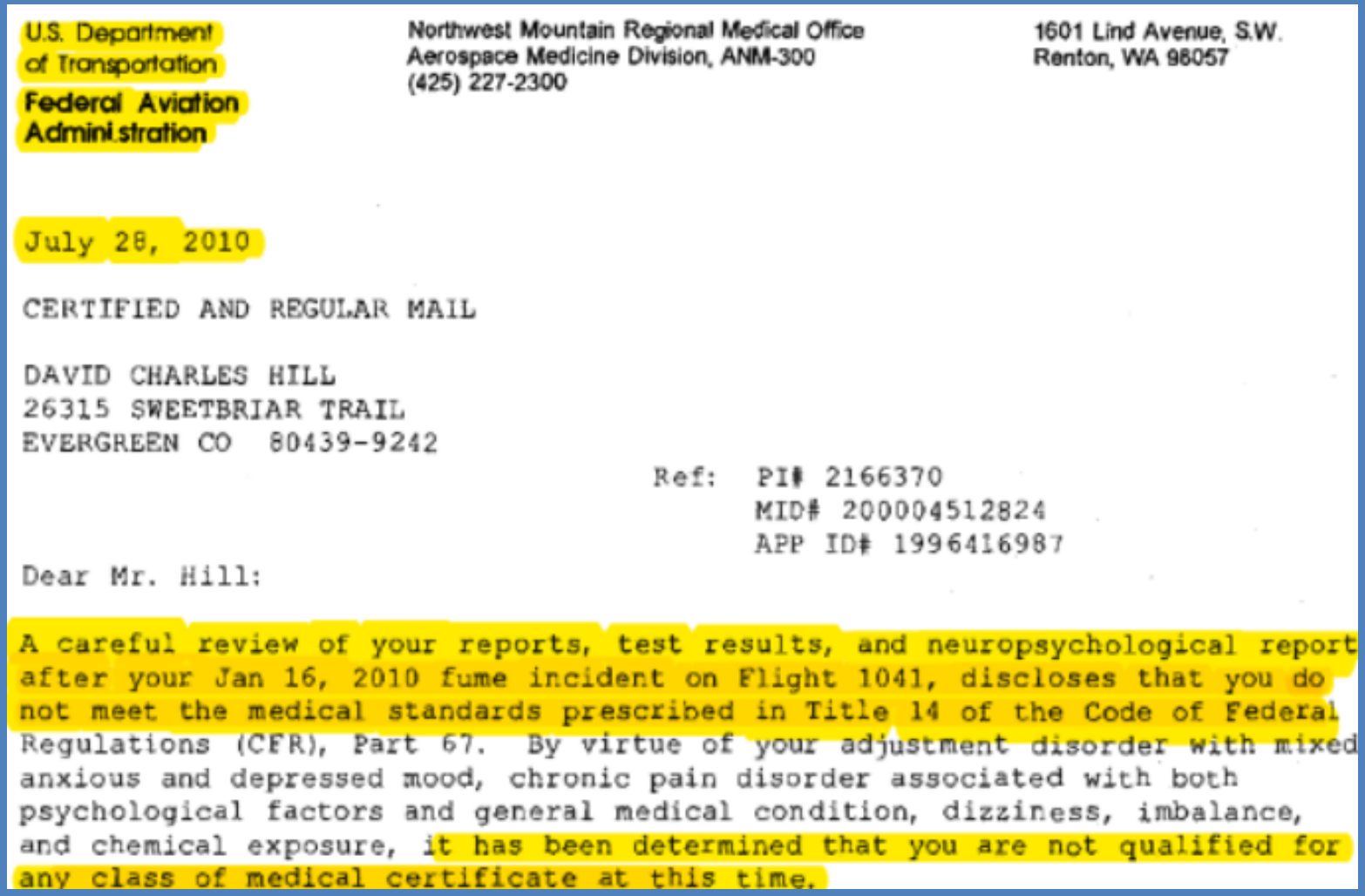
4. Problem Description (Note: Please limit your description to 1500 characters.)

CLT FLT 1041, DURING THE FLIGHT, MULTIPLE CREW MEMBERS EXPERIENCED SYMPTOMS OF POSSIBLE AEROSOLIZED FUMES FROM CABIN AIR. SUSPECT THE RIGHT RESERVOIR WAS OVER SERVICED DUE TO POSSIBLE BAD CONNECTOR (D60) SHORT (SHIELDING DAMAGE). REPLACED CONNECTOR AND SERVICED RESERVOIR TO PROPER LEVEL. REPLACED TRANSMITTER (AS A PRECAUTION). BORESCOPED LEFT AND RIGHT HPC BLADES FOR WETTING, NONE FOUND. REPLACED RECIRCULATION FILTERS. CHECKED OPERATION OF LEFT, CENTER, AND RIGHT PRESSURE MODULES RESERVOIR. OPERATIONS GOOD.

- The aircraft mechanical records confirm that oil contaminated the bleed air during that flight and the aircraft had a history of smoke/fumes.

Compromised flight safety: Jan. 16, 2010

- In July 2010, the FAA took Captain Hill's license because he was not fit to fly.



U.S. Department of Transportation
Federal Aviation Administration

Northwest Mountain Regional Medical Office
Aerospace Medicine Division, ANM-300
(425) 227-2300

1601 Lind Avenue, S.W.
Renton, WA 98057

July 28, 2010

CERTIFIED AND REGULAR MAIL

DAVID CHARLES HILL
26315 SWEETBRIAR TRAIL
EVERGREEN CO 80439-9242

Ref: PI# 2166370
MID# 200004512824
APP ID# 1996416987

Dear Mr. Hill:

A careful review of your reports, test results, and neuropsychological report after your Jan 16, 2010 fume incident on Flight 1041, discloses that you do not meet the medical standards prescribed in Title 14 of the Code of Federal Regulations (CFR), Part 67. By virtue of your adjustment disorder with mixed anxious and depressed mood, chronic pain disorder associated with both psychological factors and general medical condition, dizziness, imbalance, and chemical exposure, it has been determined that you are not qualified for any class of medical certificate at this time.

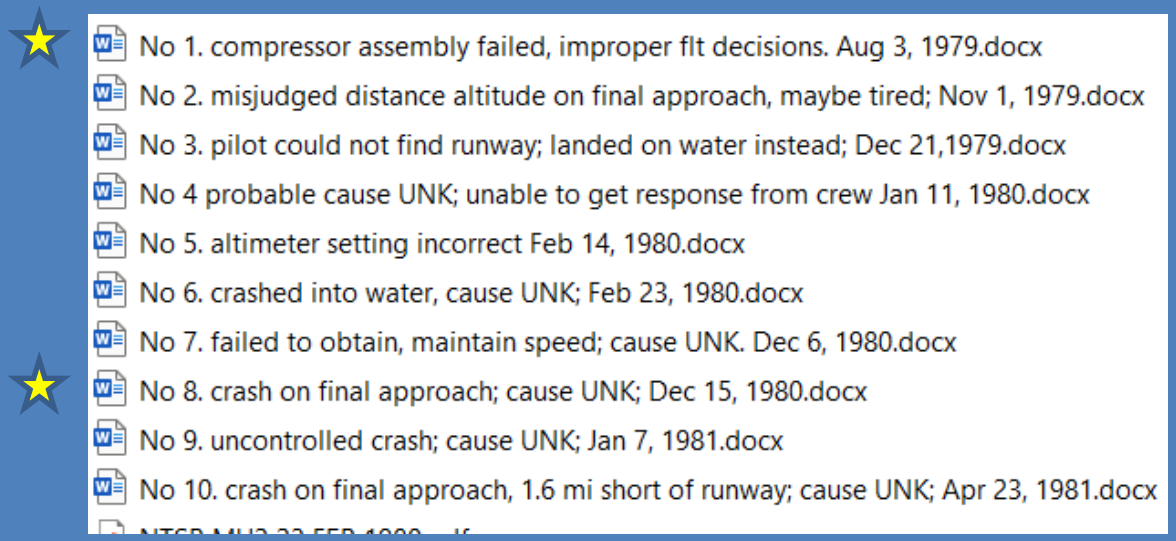
Compromised flight safety: Jan. 16, 2010



- In Jan. 2013, the airline denied his compensation claim.
- And in Dec. 2019, in despair, he shot himself in the head.
- He lost his life. The lives of the other crewmembers have been damaged – all extremely sad. On subject of flight safety, Captain Hill and his First Officer were impaired during descent and landing. They said that they could easily have taken down the entire plane with the crew and 216 passengers on board.
- If they had done so, what would the accident report say?

Probable causes? “Undetermined”, “unknown”, “miscellaneous”, etc.

I think it would say something like this: That the aircraft had a history of fumes. That the pilots made mistakes – they stopped responding to ATC, forgot to put down the landing gear. There was oil residue on the inside of the ECS. Someone may even propose a hypothesis to the NTSB. And the probable cause would be undetermined.



What is the core message to the NTSB, FAA, and industry?

Put flight safety before cost savings.



Thank you for your attention.

Judith Anderson, MSc CIH
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Air Quality: The State of Standards

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Abstract

Purpose: This work provides an overview, from a Consumer perspective, on how the problem of Cabin Air Quality is being addressed through the development of an International Standard. The author is neither a scientist, engineer nor pilot, but has had to engage with each of those disciplines and determine how a better outcome can be achieved for ordinary airline passengers and for the air that they breathe. The paper concludes on hard-law versus soft-law and the serious issues that need to be addressed, because the issue of contaminated Cabin Air and Standards must surely be at the crossroads?

Methodology: The author's extensive experience in the work of Standardisation and dealing with direct Consumer contact, across two continents, has been critically examined to provide an overview and analysis of the current benefits for Consumers.

Findings: The issue of contaminated Cabin Air has developed an International "Standards" circus where politics, commercial politics and the possibility of solutions, constantly challenge the challengers. There is a difficulty in a rule-based Standards-making system that fails to adequately deploy methodology and define adequately what constitutes a consensus. This paper highlights those difficulties and raises a number of challenges that if resolved, may deliver a Standard of benefit to an Industry and the occupants of an aircraft. The alternative is a hard-law solution.

Research Limitations: This paper is limited to the work, view and opinions of one independent Consumer Campaigner. But, the subject matter is also limited by the scant attention paid by many European Consumer Organisations to this work. Current EU Standardisation Regulation only recognises Consumer "Establishment" Organisations.

Practical Implications: This paper has important methodology implications for the future of European Standardisation and the potential for its work on contaminated Cabin Air. It also raises important questions about the state and status of Aviation Regulation in the EU.

Social Implications: The commentary in this paper has the potential to alert the EU Consumer Organisation Industry as to the complexity of issues on contaminated Cabin Air, and the process of achieving Consumer protections either through hard-law or soft-law. It also has the potential to raise awareness amongst Consumers globally as to the nature of Cabin Air Quality.

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Value and Originality: The originality of this paper is founded in the experience of its author, and its ability to highlight key issues that have the potential to lead to a solution to the long-standing problem of contaminated air within aircraft.

Keywords

cabin air quality, aircraft, travel, holidays, flight, consumer rights, consumers, air passengers, activism

1 Introduction

My first foray into Cabin Air Quality came in 2006, when I met a group of passengers who had experienced a problem during their flight from the UK down to Florida. A number of passengers were overcome by fumes on their flight and suffered with post-flight problems, not just in their resort, but when they returned to the UK. Some suffered with nerve or concentration problems, others spoke of respiratory issues; a small number suffered with long-term health-problems.

I quickly became engaged with the pilot and flight-attendant community and realised that this had been a major issue over many years, that had affected so many aircrew, and as I was to discover, so many passengers. Whilst science had evaded my own early education, I had to acquire new skills, just to be able to maintain a position in this new conversation; I now know more about the workings of a jet-engine than I do of the engine in my car! I also discovered that within the Consumer representation community, there were few, if any, who were aware of the phenomena of contaminated air in aircraft.

Along with my new colleagues, I explored the route to 'hard-law' (that is a law that obligates a State, an individual or company to carry out a particular act), but I quickly discovered that in the field of Aviation, whilst there may be structural 'hard-laws', the majority of 'obligations' was to be found in the mechanism of 'soft-law', structured through Standards. Such Standards are generally voluntary and not-binding, the knowledge of which was met with incredulity by passengers affected by a fume event, after returning from their holiday in Bulgaria.

I also realised that many of the Standards created were formed in the company of a Regulator and Industry and sometimes with non-aviation 'establishment' bodies; I realised that the wider cohort of aircrew and passengers were notably absent from the conversation. So, I found myself representing passengers in the United States and within Europe, bringing to the table the experiences of real people, the ones who sit at the back of the aircraft, and their obvious need not to enter into an environment that may adversely affect them.

In this paper, I am going to talk about my experiences with Cabin Air Quality and the State of Standards; the State being the principal backer of Standards work and the actual state of Standards.

2 So why Standards?

Standards are viewed as consensual solutions to the myriad of engineering and technical issues that can arise on aircraft. Standards are generally seen as a softer option against hard law, in an effort to create a wider compliance and perhaps innovation. They are attractive to legislatures because they potentially take the hard work out of law-making. Standards are generally non-binding and have no legislative force, but they are potentially persuasive on compliance where a complaint or problem arises on an aircraft. The argument made by Campaigners was this: *"If we have no immediate opportunity to create hard obligatory law, then we should as important stakeholders, have a seat at the Standards top table to direct and influence their content"*.

As a result of my work with Consumers, I became engaged in the work of Standards, initially in the United States[1], along with work in the UK[2] and in Europe[3].

3 The Cultural Divide

The experience in the United States is interesting, this is because I began to recognise the cultural differences that exist between the USA and Europe. This ranges from attitudes toward regulation/deregulation, to how businesses are run and how employees of those businesses engage with workplace issues. It has been vital to understand these differences because they help to inform why positions are taken and the potential route to engagement; it has been a mediation masterclass without the formal training!

To give you an example of some of the difficulties, there are times when I have felt that the Consumer point of view has been drowned out. But then if you are suggesting the introduction of the Precautionary Principle[4] into an American Standard, you'd better be prepared for the almost apoplectic reaction to your proposal.

4 The Use of Ground-Based Thresholds

Another example can be found within the debate on ground-based thresholds; their potential use in the aircraft environment provides for an abstract debate. So for example, it has been offered that current thresholds do not deliver consideration of the 'emergency' conditions that arise from a fume event. It has been suggested that the nature of the 'emergency' leads to different considerations, and that current thresholds should reflect such an 'emergency', adopting the levels (which would represent an increase found in the current Standard), in line with the US Department of Energy, Health, Safety & Security's, Protective Action Criteria (PAC) emergency thresholds[5]. If we followed that logic, for example, the Carbon Monoxide (CO) threshold could increase threefold from the current stated levels; is this acceptable? Now I have deliberately chosen CO because I wondered what might be the motivation behind this move? I could be wrong, but the United States may pass/implement a Cabin Air Safety Act (2019)[6] (currently it is passing through the US Congress). Within that Act there is a requirement that would obligate airlines to fit Carbon Monoxide (CO) sensors. I can see the concerns of airlines, worried that CO sensors (with a low threshold limit), could deliver repeated warnings which may affect the viability and operations of that aircraft. It therefore raises the point; would the proposed increase in the CO threshold level within a Standard, ensure that the sensor would not be activated so often; how does that benefit the occupants; do airlines already know how much CO is present on any given flight?

5 The European Experience

Remember, standards-making shifts debate away from any 'hard law' requirements and has delivered a global standards-circus, where we criss-cross time zones to deliver documents that hopefully provide value and fairness for all. In Europe, as campaigners, we challenged the orthodoxy of a published Industry standard, as not reflecting the reality of flight nor indeed the participation of a wider stakeholder cohort. That standard was overturned and new work began in 2015 to create a European Standard. In the beginning, it was difficult, with both sides entrenched, but European politics always delivers on engagement and consensus. In 2020, despite the challenges of COVID and over 1,100 Public comments, we produced a draft Standard of value: **CEN prEN 17436** [7,8,9]. The document delivers series of mechanisms

1 https://www.techstreet.com/ashrae/standards/ashrae-161-2018?product_id=2001169
2 https://standardsdevelopment.bsigroup.com/committees/50256465
3 https://www.cencenelec.eu/european-standardization
4 https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2000:0001:FIN:EN:PDF
5 https://www.energy.gov/ehss/protective-action-criteria-pac-aegls-erpgs-teels
6 https://www.congress.gov/bill/116th-congress/house-bill/2208
7 https://perma.cc/S7AD-5G7J

(or a hierarchy of controls) all under the watchful umbrella of the Precautionary Principle. This document does not contain thresholds, because that is what ALL the stakeholders agreed we should do, we also went beyond the pass/fail criteria argument. Our work delivered due care, due diligence, along with consensus from every single sector in this debate. The current draft Standard presents the very best of solutions, where formal European regulation has thus far failed.

Through this process in 2020, we began to see the emergence of a press narrative that demonstrated that some wished to resile from the previous position of consensus. Equally, during the process of the last two years, some external letters were received on cabin air quality. Some of those letters were brought to our attention; some I have subsequently been made aware of. Whilst I could certainly provide extensive commentary on the issues that were raised, I will not do so at this time simply because I wish to respect the fact that they appear to be protected by privacy. But from what I have seen, in my opinion, some contain matters of important public interest warranting at least some form of debate. Currently this is a matter for others to deal with!

Despite these interventions, there was a clear palpable fear from some that this Standard would enter the lexicon of Aviation laws, but given that the many laws they refer to as "regulation" such as CS (Certification Specifications)[10], AMC's[11] (Acceptable Means of Compliance), AltMoc's (Alternative Means of Compliance), are in fact voluntary, non-binding and, have no legislative force, their fear is somewhat redundant. As COVID entered our lives, some wanted to suspend the work.

At the end of 2020, when many expected that the draft Standard would go out for a formal vote, potentially leading to publication, we all experienced an interesting commentary and some surprises on the outcome of our expectations. A decision was made, not by the experts on the Standards Committee, but for and on behalf of the experts, as to what would next happen to the draft Standard and its future direction of travel, leading to yet another Public Enquiry. The arguments I heard to support this action stemmed from some wanting to give those 'not in the room' the opportunity to submit their own points of view or, a lack of consensus or, a claim of reliance on the so-called 'Salon' case as reasons for not sending the document out to member states for a decision toward publication.

The 'not in the room' argument simply fails because aviation manufacturers and airlines have all been actively engaged in the global-standards-circus, they would have to be socially isolated not to have heard and read of the existence of this European Committee; in any event, they had verifiable representation from the early days on this Committee.

A claim for a lack of consensus also fails because the facts speak for themselves; we had come to trust each other and had defined a clear process that delivered for all voices through due diligence.

6 The Salon-Case[12] Argument

The Salon argument demonstrated a misunderstanding of this interesting Standards case, which was essentially a dispute between two standards technical committees. One committee claimed that the other's published standard should not stand because some of its measures needed to be carried out by qualified people. However, in my opinion, the important argument challenged that this published standard failed to protect the health and safety of EU Citizens. The case simply had no analogy to our present circumstances because of the consensual nature of our work and of the extensive debate on safety leading to the universal acceptance of the Precautionary Principle. As we all struggled to deal with this new direction of travel, I also discovered two other important issues.

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8 https://eurecca.eu/post/european-aircrew-passengers-welcome-completion-standard-aircraft-cabin-air-quality
9 https://www.eurocockpit.be/news/support-new-standard-cabin-air-quality
10 https://www.easa.europa.eu/faq/19026
11 https://www.easa.europa.eu/document-library/acceptable-means-compliance-amcs-and-alternative-means-compliance-altmocs
12 https://www.top-normy.cz/users/files/procesy-tn/CEN-CENELEC-Refit.pdf (Search for 'Salon')

7 Fuel Tank Inerting System

The first related to the Fuel Tank Inerting System[13,14], delivering a separation of bleed-air gases and compounds, so providing an inert gas for the fuel tanks on aircraft. It caused me to ask, if this separation technology (to remove chemical compounds or harmful gases) already exists, then why had this not been discussed since 2015?

8 The James Elliot Case

The second point relates to a case that came before the European Court of Justice in 2017, which declared that mandated/harmonised Standards, attached to European Regulation, should also be considered as law. This decision has already had a profound effect on the European Standards world and I suspect there is some reticence from Companies who had been given up-to-now, free-rein to define their operations. It got me thinking. The Treaties of the EU provide a division of labour and competency for the benefit of the Union and the Single Market. One competency is Aviation. EASA has been given that competency by the EU to make regulation. Therefore, if you follow the logic of this case, the 'standards' attached to formal regulation, those being CS's, AMC's & AltMoC's, must therefore be logically mandated and harmonised, and should surely now be classed as formal law, with all their apparent imperfections?

In my opinion, it presents an opportunity for Trade Unions and Consumer Organisations across Europe, who should begin the conversation and challenge the status of European Aviation Standards, utilising the arguments and logic of this case *(James Elliot Construction - Aggregate - Could the court adjudicate on a harmonised standard?* [15]*)*. Would this not create a sense of purpose and legal certainty; what about benefit to pilots and cabin-crew and ultimately the passengers?

9 Pressure Points

In conclusion, we are now faced with a number of pressure points:

1. Recognising the extensive risks that exist in standards-making against the risks faced by the occupants of aircraft (Vested Interests/application of rules);
2. In Europe, finding a way to restore consensus, trust and once again determining ethical intentions;
3. As we subscribe to standards-making rules and ethics, how we can ensure that the work guarantees process, enforcement, oversight, courage or stability?
4. Will we once again have to respond to the desire for a performance-based or thresholds Standard?
5. Should we claim a necessary & properly formed methodology, clear & open analysis and a recognition of a wider European Union process?
6. Will this work lead to arguments without end when all thought that such arguments had been resolved by consensus?
7. From a personal perspective, if a process produces difficulties that could ultimately deliver detriment to Consumers, is it right to continue to legitimise that process?

These are difficult questions but they are now accompanied by the need to carry out a continual risk assessment of any standards-making process; it is no longer an option not to risk assess this work.

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13 https://www.faa.gov/regulations_policies/rulemaking/committees/documents/media/ECfthwgT1-1231998.pdf

14 https://www.collinsaerospace.com/what-we-do/Business-Aviation/Power-Controls-Actuation/Actuation/Composites/Fuel-Systems/Fuel-Tank-Inerting-Systems

15 http://curia.europa.eu/juris/liste.jsf?language=en&num=C-613/14

10 Conclusion

Looking forward, I think there are several immediate challenges ahead:

1. The challenge of the appropriateness of ground-based thresholds against the failure to properly define the uniqueness of the aircraft environment; there needs to be a hierarchy of argument;
2. EU Aviation law/standards provides a presumption of compliance, which is a flawed regulatory concept, because it imports the 'benefit of the doubt' argument, resoundly rejected by the Precautionary Principle - is this the ultimate direction for this Standard? And finally;
3. We as Campaigners have in my opinion taken our eyes off the 'regulatory' ball, and I hope others will join me in creating a formal European Regulation on Cabin Air Quality.

In my opinion, the State of Standards is now at a crossroads, what we do next is important for all.

About the Author

Frank Brehany. I am a dual-Citizen, one of which delivers a long-standing European Citizenship. I am a medically retired Police-Officer and qualified in 1997 as a practising Solicitor, working initially in formal legal practice, this lead to ownership and management of a National Consumers Organisation. My interests in Law covers not just Consumer Law, but also the problems found within Consumer Contracts, European Law, Human Rights and National and cross-border solutions to Consumer problems. I have extensive media experience, and comment on Legal issues for Consumers, Travel Trends and the Travel related problems experienced by Consumers.

I continue as a self-funded practising solicitor, not currently working in Legal Practice, but I maintain my competency as required by the Solicitors Regulatory Authority of England and Wales.

I apply my legal training and experience, to help develop solutions within the Standards-making and Political environments. I have never been a member of any political party or grouping and I voluntarily subscribe to the Nolan Principles for Standards in Public Life.

My legal work has always been about the day-to-day Consumer or Victim-related issues, but now I work in arguing both practically and politically for change on Cabin Air Quality. I have now published a book for Consumers to raise awareness of this issue: "Gaspers: Clean Air for Passengers?" [16]

[16] https://www.amazon.com/dp/B09B1L1PTS

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Aerotoxic Syndrome, the Heart and Organophosphates

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Abstract

Purpose: The purpose of this presentation is to increase the awareness of the cardiac effects of OP toxicity in aircrew exposed to FEs. Two case vignettes of aircrew experiencing OP toxicity as a result of FE exposures are presented as an introduction to the subject of the present paper.

Keywords

aerotoxic syndrome, cardiac disease, organophosphates

1 Introduction

Aerotoxic Syndrome was first described by Winder and Balouet [1] in 2000 to describe a collection of predominantly neurologic and respiratory symptoms experienced by aircrew following exposure to pyrolysed jet engine oil leaking into the bleed air and thus contaminating the aircraft cabin air (fume events – FEs). These fumes contain a cocktail of volatile organic hydrocarbons many of which are known to be toxic including organophosphates (OPs). The latter are included in jet engine lubricating oils as an anti-wear additive. Since the original description, medical complaints affecting all organ systems have been recorded following a FE [2]. The effects of exposure may be transient, prolonged and sometime permanent. The term and existence of 'Aerotoxic Syndrome' is criticized by some groups but the authors have used in the present context as it is the term used in the original publication [1].

2 Case presentations

Case 1: A 34 year old male pilot who had been exposed to three FEs over a three month period about two years prior to presentation was seen complaining of symptoms of nausea, light-headedness, foggy thinking, cognitive dysfunction, fatigue tremor, grey skin, eye irritation, cough, breathlessness and palpitations. The latter increased with exercise. A detailed cardiac assessment showed a rapid irregular heart rate at rest with frequent ventricular ectopic beats.

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Review process: Editorial review. The corresponding author is marked with *.
Related presentation: https://doi.org/10.5281/zenodo.4730409

Case 2: A 41 year old female flight attendant presented following a significant FE event complaining of mild headache, nausea, dizziness, cough, breathlessness and palpitations. She was also suffering from balance and gait difficulties, poor short-term memory and cognitive impairment. Her dizziness, particularly on standing up, and palpitations continued and when examined four years later a diagnosis of Postural Orthostatic Tachycardia Syndrome (POTS) was made.

3 Organophosphate poisoning – general comments

Organophosphate toxicity is well known in the general community and is usually the result of poisoning following their use in agriculture (pesticides and herbicides) but accidental and suicidal poisonings are not uncommon. Inhalation is the usual portal of entry but OPs may also be absorbed through the skin, conjunctivae or ingested. With these exposures cardiac toxicity is common and usually manifested by ECG changes, myocardial damage with impaired cardiac function, abnormal cardiac rhythms some of which are serious enough to cause death. Other toxic effects of OPs include cough, breathlessness, chest pain/tightness, salivation, tearing, sweating, nausea, vomiting, diarrhoea, headache, visual disturbance, confusion and cognitive impairment, tremor, dizziness, loss of balance and sometimes coma. Most poisonings in the agricultural and community follow large and usually accidental exposures and serious cardiac abnormalities are frequent [3,4]. Death from accidental and suicidal intent are well recognised [4].

Toxicity is largely related to myocardial irritability manifested by cardiac rhythm disturbances, such as slow, rapid (palpitations) or irregular heart rates. Electrical abnormalities of the heartbeat are also common, for example ST-T wave changes and Prolonged Q-T Syndrome, the latter which may prompt life threatening arrhythmias, such as atrial fibrillation, ventricular tachycardia or fibrillation and Torsades de Pointe with the latter two causing death if not promptly treated.

4 Aerotoxic Syndrome, the heart and organophosphates

OP cardiac toxicity has long been recognised in the non-aircraft setting but in the fume event setting it attracts less consideration and is infrequently recognised by the medical profession. The reason for this is probably due to OP concentrations being significantly smaller in cabin air after a FE in comparison to that found in agricultural and industrial settings. FE may also affect passengers and very low exposures to the OP tri-o-cresyl phosphate have been reported [5]. As a result of the smaller cabin air OP concentrations, cardiac abnormalities are much less frequent.
While there are no systematically documented reviews into the alterations in heart rate and/or blood pressure after FEs, cardiac abnormalities reported by aircrew after FEs have been documented [2].

Higher rates of heart disease have been reported by flight attendants exposed to cabin air contaminants in one study suggesting that they may be related [6]. However, this association was not confirmed in a later study [7].

In the community setting and at the pathological level, patchy myocardial and pericardial damage has been reported in acute OP poisoning as a result of direct cardiac toxicity and may be a factor in serious cardiac complications. The authors warn that these findings may not result in ECG or echocardiographic changes and, for this reason, cardiac monitoring is warranted [8].

An aircrew postmortem study identified lymphocytic myocarditis, which was thought to be related to OPs [9]. A UK coroner referring to other aircrew postmortem cases noted that, in two cases of young fit aircrew, there was evidence of lymphocytic myocarditis and peripheral nerve damage [9]. In another report, a left ventricular myocardial biopsy showed the histological features of a toxic myocarditis [10]. For obvious reasons, as cardiac diagnostic procedures, e.g.

ECG, echocardiogram recordings, stress tests and myocardial perfusion scans, are not routinely undertaken prior to or in-flight, the pre-mortem cardiac status of affected persons has not been described.

Thus, it is clear that OP exposure may lead to cardiotoxicity following a FE and has been shown to cause rhythm disturbances and myocardial damage. As the latter may be present in the absence of clinical signs and ECG changes, it is important to consider more detailed cardiac investigations in all cases, particularly if cardiotoxicity is suspected.

5 Summary

In summary, OP induced cardiac toxicity is common in the general agricultural community where significant exposures occur as a result of the use of herbicides and pesticides. Present knowledge suggests it is less frequent in association with aircraft cabin FEs but the current literature is limited on the subject and there have been no systematic studies conducted. Experience and the limited literature suggests that FEs may cause cardiac abnormalities and that these may be transient or long standing. More studies are needed.

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Aerotoxic Syndrome, the Heart and Organophosphates

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Introduction - Aerotoxic Syndrome

- First described in 2000 by Winder and Balouet
- Describes collection of predominantly neurologic and respiratory symptoms in aircrew
- But medical complaints affecting all organ systems recorded
- Caused by inhalation of pyrolysed engine oil leaking into bleed air and then to incoming cabin air
- Effects may be transient, prolonged or permanent
- Existence and terminology criticised by some groups

Clinical Vignette – Case 1

- 36 yr old male pilot
- 3 FEs over about 3 months
- Presenting symptoms:
    - Nausea, light headedness, foggy thinking, cognitive dysfunction, fatigue, shaking, grey skin, eye irritation, cough, breathlessness and palpitations
- Palpitations increased with exercise
- Cardiac assessment:
    - Rapid irregular heart rate at rest,
    - Ventricular ectopic beats
- Symptoms continue 2 years after exposure

Clinical Vignette – Case 2

- 43 yr flight female attendant
- FE on long haul flight to LA
- Complained many symptoms including:
  - Mild headache, nausea, dizziness
  - Memory and cognitive impairment
  - Breathlessness, cough and palpitations
- Palpitations now longstanding
- Has developed postural orthostatic tachycardia syndrome (POTS)

Organophosphates (OPs) – General Comments

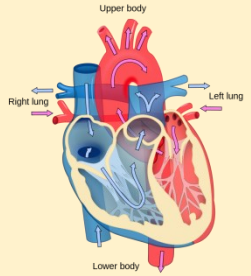
Organophosphates

- Commonly used in pesticides & herbicides
- Also as anti-wear additive in gas turbine engine lubricating oils
- Tri-cresylphosphate known neurotoxin
- Mode of contact in OP poisoning usually:
    - Agricultural
    - Accidental
    - Suicide
- Exposure by inhalation, ingestion, dermal, conjunctival

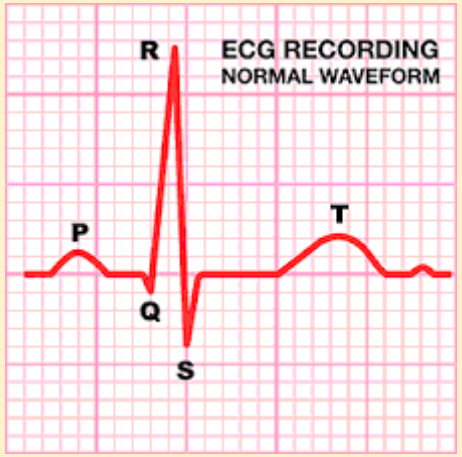
Organophosphate (OP) Toxicity

- Most poisonings associated with large exposures
- ~ 3 million+ exposures with ~ 300,000 deaths annually world wide
- Multisystem toxic effects including
    - Headache, paralysis, loss of balance, visual
    - Confusion, cognitive impairment, tremor, dizziness, coma
    - Cough, breathlessness, chest pain/tightness
    - Salivation, tearing, sweating
    - Nausea, vomiting, diarrhoea

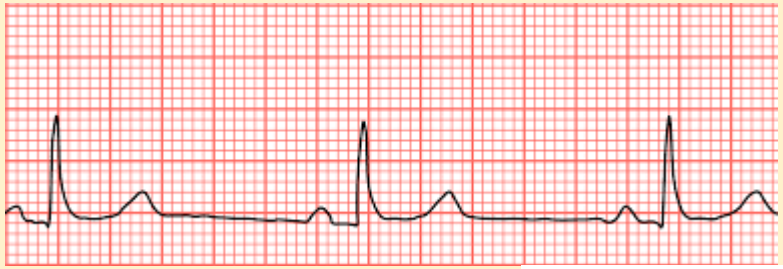
Organophosphates (OPs) and the Heart (1)

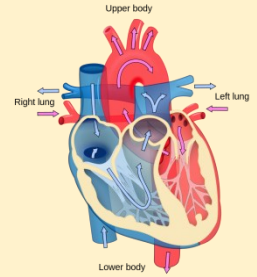


- Cardiotoxicity long recognised in non aircraft setting
- Largely related to myocardial instability and rhythm disturbances
- These include:
    - ECG abnormalities –
        - Elevation S-T segment
        - Prolongation of QT interval
    - Sinus bradycardia (slow) & tachycardia (rapid) heart rates

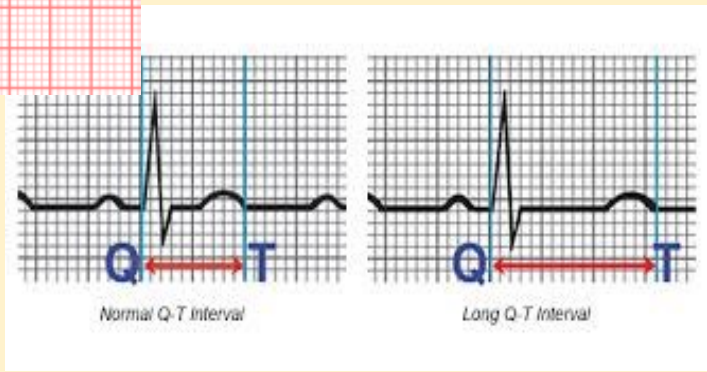

ECG RECORDING
NORMAL WAVEFORM
R
P
Q
S
T

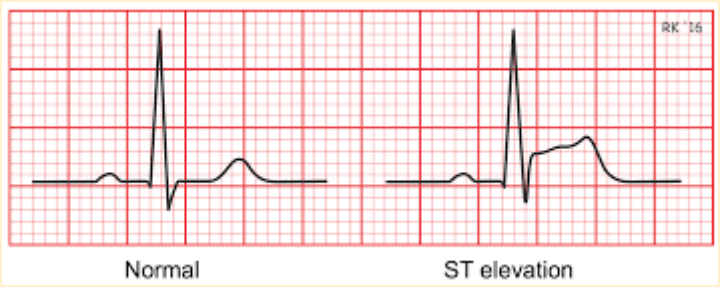

II

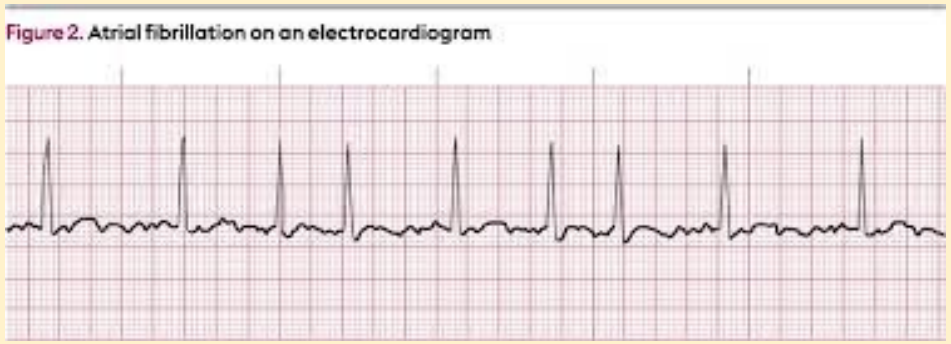


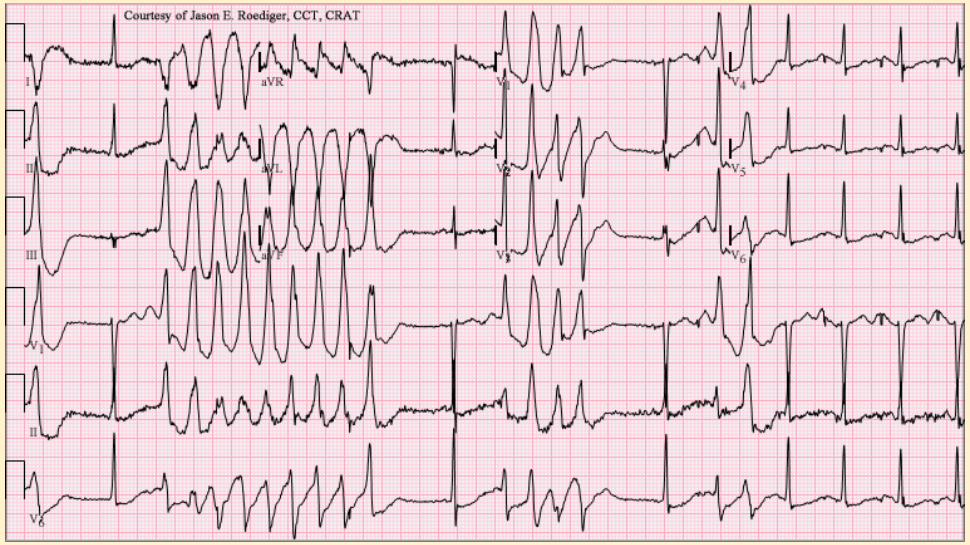

Upper body
Right lung
Left lung
Lower body



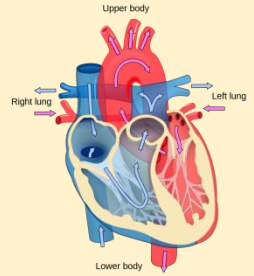

Q
T
Normal Q-T interval
Q
T
Long Q-T Interval


RK '16
Normal
ST elevation


Figure 2. Atrial fibrillation on an electrocardiogram


Courtesy of Jason E. Roediger, CCT, CRAT

Organophosphates (OPs) and the Heart (2)



- Conduction defects
  - Abnormal electrical messaging from atrium to ventricle
    - Irregular heart rates
      - Atrial fibrillation
      - Ventricular tachycardia
      - Ventricular fibrillation
      - Torsades de point
  - May lead to sudden death
- Myocardial damage – oedema, vascular congestion, inflammation, blood clots, heart failure, death

Useful References:

- Roth et al. Organophosphates and the heart. Chest 1993;103:576-582
- Anand A et al. Cardiac abnormalities in acute OP poisoning.
  Clin Tox 2009;47:230-235

OPs, Fume Events and the Heart

Fume Events and the Heart (1)

- Exposure concentrations much lower than in most community OP exposures
- VOCs when measured in aircraft cabins less than industry accepted standards
- Note these standards do not protect all exposed
- Ultra-fine particles known to exacerbate cardio-respiratory disease

Fume Events and the Heart (2)

- Cardiac effects appear less commonly after FEs
- Less well known
- May not be recognised in many cases
- Largely related to myocardial instability and arrhythmias
- No studies immediately after an FE
- Knowledge comes mostly from case based studies and systematic reviews

Fume Events and the Heart (3)

- Studies of aircrew have shown
  - Atrial and ventricular ectopic beats - palpitations
  - Coronary artery disease ~2.5%
  - Hypertension ~25%
  - Chest pain/tightness up to 33% (included palpitations and hypertension)
  - Several reports of Lymphocytic and Toxic myocarditis

Organophosphates - Summary

- Cardiac toxicity common with significant community exposures
- Current knowledge suggests it is less frequent after a FE
- But literature limited
- Experience and the limited literature suggests
  - FE may cause cardiac abnormalities
  - Abnormalities may be transient or long standing

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Aircraft Cabin Air International Conference 2021 (ACA 2021) – Proceedings

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Conference Director: Tristan Loraine
Publisher: London, UK: GCAQE (https://gcaqe.org)
Editors: Dieter Scholz, Susan Michaelis

Investigating Health and Exposure Circumstances of Persons after Aircraft Fume Events: A Narrative Review with Medical Protocol

BURDON, Jonathan[1], BUDNIK, Lygia Therese[2], HEUTELBECK, Astrid[3], BAUR, Xaver[4], ROIG, Jordi[5], COXON, Leonie[6], MIDAVAINE, John[7], PETERSEN, Hannes[8], HAGEMAN, Gerard [9], SOSKOLNE, Colin L.[10], GEE, David[11], FURLONG, Clement[12], LORAINE, Tristan[13], HOWARD, C. Vyvyan[14], MICHEALIS, Susan[15]

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[6] Clinical and Forensic Psychologist, Mount Pleasant Psychology, Perth Western Australia
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Abstract

This document lays out a consensus approach, by internationally recognised experts, to the recognition, investigation and management of persons suffering from the toxic effects of inhaling pyrolysed engine oil and other fluids contaminating the air conditioning systems in most aircraft. A best practice medical protocol is outlined and addresses the recommended actions and investigations to be undertaken for those suffering ill-health following FEs and presenting In-flight, immediately Post-flight (within 1-2 days) and later/subsequently (beyond 2 days).

Keywords

aerotoxic syndrome, fume events, ill-health, treatment, medical protocol

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Author contributions: All authors contributed to the paper within their area of expertise. Overall review was undertaken by Jonathan Burdn, Susan Michaelis, C. Vyvyan Howard and Tristan Loraine.
Review process: Editorial review. The corresponding author is marked with *.
Previous presentation: An earlier draft of this paper was presented at the *Aircraft Cabin Air International Conference 2019.*
Related presentation: https://doi.org/10.5281/zenodo.4730406

1 Introduction

Pyrolysed engine oil fumes contaminating the aircraft cabin air conditioning systems has been recognised and well documented since the 1950s. It is now clear that inhalation of these potentially toxic fumes in aircraft cabins causes ill-health. There is a clear and well documented history linking the onset of ill health with fume exposure in most cases. It is now clear that cumulative exposure to regular small exposures is also damaging and may be exacerbated by a single more concentrated exposure. Whilst organophosphates have been the main subject of interest, it is also clear that there are numerous volatile organic hydrocarbons in the aircraft air supply, which are likely, based on experience outside the aircraft industry, to contribute to this form of ill-health. Assessment is made more complex because of the limitations in looking at individual substances in complex heated mixtures.

The lack of acceptance of illness caused by exposure to pyrolysed engine oil, de-icing and hydraulic fluid in bleed air and aircraft air supplies is likely to be due to lack of knowledge and clinical acumen. The easier finding of more clinically acceptable diagnoses in unexplained clinical presentations is recognised.

This document lays out a consensus approach, by internationally recognised experts, to the recognition, investigation and management of persons suffering from the toxic effects of inhaling pyrolysed engine oil and other fluids contaminating the air conditioning systems in most aircraft. A best practice medical protocol is outlined including actions and investigations for in flight, immediately post flight and late subsequent follow up.

The then almost completed first “final draft” of the medical protocol was presented at this Conference in 2019. Since then, the authors have updated the document with comments on emerging areas of investigation and additional medical and scientific material. The aim of the presentation at the 2021 Conference is to provide an update on further progress to date to those who attended eighteen months ago and to inform those who have not been made aware of the status of this work. The authors are aware that this manuscript has taken many years to write and acknowledge that this has been because of the moving landscape – new scientific and medical information that needed to be included and the difficulty of harnessing numerous experts who were and are already have huge demands on their time. The authors also recognise that there have been a number of Guidelines putting forward recommendations for actions to be undertaken at the time of and following a FE.

The term and existence of ‘Aerotoxic Syndrome’ was coined by Winder and Balouet in 20001 to describe the constellation of symptoms experienced by persons exposed to FEs. The term has been criticized by some groups for a number of reasons. However, the authors have used here as it is the term used in the original publication1.

2 Technical Matters

There is a medical need to recognise and understand a number of technical issues that that are raised in the context of FEs.

It is not generally understood in the medical community that the aircraft cabin is a closed environment with a high human occupancy and that outside air is being used to flush the cabin air and assist with pressurisation. In this regard it is different from a modern sealed building as air exchange rates are greater than in commercial and other modern buildings. This air enters the cabin through the engine and may be contaminated by pyrolysed engine oil leaking through oil seals except in the Boeing 747 Dreamliner which has an air supply independent of the engine.

It is also important to recognise that there are no fine lines separating those who will experience ill-health during or after a fume event and those who are not affected. The regular defence used by industry is that environmental concentrations of toxic substances are all below industry accepted standards. This defence ignores the fact that these standards are set to protect most persons exposed but not all. Furthermore, these standards are not available for all pyrolysed substances, all have been set for ground level and, thus, cannot be extrapolated to the cabin environment and take no account for altitude nor pyrolysed complex mixtures.

3 Medical Matters

The medical presentations of persons who have been exposed to FEs are variable and well-described in the literature2. In summary, these initially, and consistently, involve the symptoms of foggy thinking, dizziness, recognising an odour in the cabin, (commonly described as a 'dirty socks' smell), impaired short-term memory and cognitive thinking, fatigue, headache, nausea, tremor, balance, incoordination, breathing difficulties, cough, chest pain, eye, nose and throat irritation. Many other symptoms, with a delayed onset, have also been reported, but the common factor that binds both the acute and delayed complaints is that they are all consistent with volatile organic hydrocarbon and organophosphate toxicity.

Medical management is related to the presenting symptomology at the time of examination and specific investigations will vary in each case, depending on specific technical and individual contextual factors. The duration of ill-health is very variable. Symptoms may last for hours, days, weeks or months. Sometimes full recovery never occurs. Persons with ongoing symptoms should ideally be followed-up and reviewed by experienced medical professionals. Our publication outlines ongoing management and investigation in detail.

The time of presentation of illness following a FE is important. Symptoms characteristically occur in one of several time frames being:
In-flight
Immediately post-flight (within 1-2 days)
Late/subsequent (beyond 2 days)

It is important that careful records are kept at the time of exposure to a FE as these will assist with ongoing medical management. In particular, these include:
the physical aspect of the exposure (type of aircraft, where if the aircraft, stage of flight, smells/odours etc)
a careful medical record of symptoms and signs, oxygen use, any treatment given, history of flying (log books etc).

4 Emerging Areas

A number of matters germane to the subject of FEs and Aerotoxic Syndrome have come to the authors' attention during the ongoing development of our manuscript. These include the recognition that fine particles affect health and that ultrafine (nanoparticles) are now accepted as being more toxic. Experience has shown that low level fume exposures are almost certainly occurring on a regular basis and that they almost certainly have a cumulative effect. These observations underscore the need to improve air quality standards in aircraft.

5 Medical Protocol

Since our last presentation of this manuscript in 2019 a significant amount of additional material has been added. These include additional material and expansions of the following sections:

- Neurology and neurotoxicity
- Best collection times for anticholinesterases
- Effect of anticholinesterases on different nervous systems
- Effect of recurrent and cumulative low dose exposure
- Effect of ultrafine (nanoparticles) particles
- Association with fatigue, sleep disorders, infection, malignancy, visual disturbance, arthritic symptoms
- Other possible associated conditions eg malignancy, chemical sensitivity

6 Summary

In summary, the medical protocol is now completed and in the editing phase. The authors accept that it has been a long journey but have wished to make the work the most comprehensive to date. It is a consensus document prepared by internationally recognised experts in their fields. A pocket size booklet is also being prepared for easy portability and reference at the time of a FE.

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WINDER, C. Balouet J-C. 2000. *Aerotoxic Sydrome : Adverse Health Effects Following Exposure To Jet Oil Mist During Commercial Flights. In: Eddington I (ed) Towards a safe and Civil Society.* Proceedings of the International Congress on Occupational Health Conference. 4-6 September, 2000. Brisbane.

MICHAELIS, S., BURDON, J. and HOWARD, C.V., 2017. *Aerotoxic Syndrome : A new occupational disease ?.* Public Heal Panor. vol. 3, pp 198–211.

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International Aircraft Cabin Air Conference, London 15-18 March 2021

Background and Overview

- Term ‘Aerotoxic Syndrome’ - Not accepted by some
- Aerospace industry does not like term
- Not all present with same symptoms
- ‘Aircraft related illness’ suggested (CASA EPAAQ 2012)
- For now term ‘Aerotoxic Syndrome’ reasonable & justifiable

Background - Guidelines

- Some past Guidelines – none comprehensive
- Acknowledged that Guidelines will vary
- Our Comprehensive Guidelines
  - Consensus view of international experts
  - About 32,000 words
  - Very near completion
  - Updated synopsis presented today
  - Pocket Guidelines will also be published separately



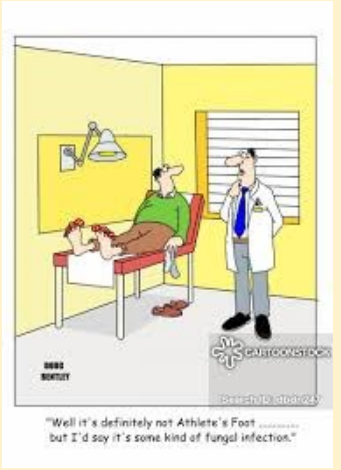
Scope of Presentation

- We are addressing
  - Bleed/supply air contaminants
    - Oils, hydraulic, de-icing fluids



- Not other pollutants
  - Pesticides
  - Infections





Technical Matters (1)

- Medical need for understanding background of FE
- Outside air used to flush cabin & assist with pressurisation
- Pyrolysed oil in bleed air - not Boeing 787 Dreamliner
- Good data assists in medical investigation/management
- Air exchange rates > than other indoor sites (sealed buildings)
- High occupancy in aircraft cabin

Technical Matters (2)

- Industry set standards

PROTECT MOST - NOT EVERYONE !

and are

- No fine lines separating healthy from unhealthy
- Not available for all substances
- Set for ground level
- Not applicable to cabin environment
- Take no account of altitude / pyrolysed mixtures

Time of Presentation / Injury

- Time of presentation with illness after FE important
    - In-Flight
    - Immediate Post Flight
    - Late / Subsequent
- Most report symptoms in-flight or immediately after
- Long-term cumulative low dose exposure (months / years) important

Presenting Symptoms

- Presenting symptoms - described elsewhere
- May involve all organ systems
- Duration
  - Hours, days, weeks, months
  - Sometimes, full recovery never occurs

Symptoms Experienced after FE - Summary

Neurotoxic

Neuropsychological

Respiratory

Gastrointestinal

Cardiovascular

Mucosal irritation

Others

Environmental Investigation of Fume Event: In-Flight

Record

- Type of aircraft
- When did event occur (stage of flight)?
- Where in the aircraft?
- What happened (smell, fumes, smoke)?
- How long did the event continue?
- Describe type of smell
- Who and how many (x out of y) affected?
- Record air quality monitor recordings (if available)

Medical Investigation of Fume Event: In-Flight

- Detailed careful history of FE including severity
- Record
  - Previous FE exposure and frequency, length of service
  - Symptoms and progression of symptoms
  - Observations of others
  - Unusual behaviour
  - Pre-existing medical conditions
  - Oxygen use (when/duration) including flow rate
  - Any treatment given/used
  - Trained medical personnel may record more

Medical Investigation of FE: Post Flight

- Medical, occupational and FE event history as before
- Will be more detailed – healthcare workers involved !
- History of career flying time (important)
- Detailed clinical examination
  - All organ systems
  - Emphasis on presenting complaints, neurological and respiratory systems
  - Mental and cognitive state important
- Special investigations - appropriate for presenting complaints

Medical Investigation of FE: Post Flight

- Special Investigations - appropriate for presenting complaints
  - Collect blood as soon as possible (record time from exposure)
  - Cholinesterases* (ideal 4-24 hrs) – *low exposure may not cause inhibition
  - Routine biochemistry, haematology, muscle enzymes
  - Others, as clinically indicated
  - Carboxyhaemoglobin **-** HbCO (within 2 hrs post flight, maximum 4 hrs)
  - Methaemoglobin
  - Collection time should be recorded **and** time from exposure.

Medical Investigation of FE: Ongoing Biomonitoring

- After immediate post flight assessment
  - Investigations based on clinical indication
  - Repeat again at week 1, 4, 12 weeks (especially cholinesterase) or symptom stability
  - Note need for repeat cholinesterase measurements (2-3 months)
  - May allow for normal assessment - Pre-exposure levels measurements unlikely.
  - Ongoing biomonitoring allows toxicological assessment relative to symptoms

Medical Investigation of FE: Ongoing Investigations

- Investigations based on clinical indication
- In particular
  - Neuronal and glial autoantibodies – indicate neuronal injury and gliosis
  - Detailed lung function testing may be needed to detect respiratory injury
  - Neurological defects – MRI scans, MRI/PET scans more sensitive
  - Neurobehavioural – Tests include Coding test (Processing speed), Problem solving, Learning, Memory, Sleep studies and others
  - Malignancy – Emerging reports of some cancers

Medical Investigation of FE: Emerging Areas

- Recognised that fine particulates affect health
- Ultrafine (nanoparticles) now accepted as more toxic
- Low level recurrent exposures probably cumulative in effect
- Underscores issue of air quality standards

Medical Protocol – Additional Material

- Sections expanded and further examined
  - Neurology and neurotoxicity
  - Best collection times for anticholinesterases
  - Effect of anticholinesterases on different nervous systems
  - Effect of recurrent and cumulative low dose exposure
  - Effect of ultrafine (nanoparticles) particles
  - Association with fatigue, sleep disorders, infection, malignancy, visual disturbance, arthritic symptoms
  - Other possible associated conditions eg malignancy, chemical sensitivity

Conclusions

- Preparation of medical protocol publication
- Long journey by many
- Some previous Guidelines and Protocols
- None as comprehensive as present
- Consensus document - Internationally expert authors
- Booklet also prepared for Guidance (What to do) for aircrew
- Be patient – we are almost there !

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An Air Accident Investigator's Perspective

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Abstract

While most investigations find evidence suggesting why mistakes happened, in some cases it seems impossible to envisage why flight crew made the mistakes that they did. Two accidents are briefly described. In each of the cases it is difficult to envisage how the experienced crew could have made the catastrophic errors that they did, unless they were impaired in some way. It appears possible that this could have been the result of ingesting oil products.

Keywords

cabin air, fumes, contamination, oil, mental capacity, error, aircraft, crash, accident

1 Introduction

Multiple cases with piston-engine aircraft where carbon monoxide poisoning caused pilot impairment and/or incapacitation have occurred. Additionally, there is an appreciable incidence of airliners suffering contamination of cabin air with fumes, often apparently due to oil entering the air bled from engines or APU (Auxiliary Power Unit) for cabin pressurisation and conditioning. It appears that synthetic oils, containing organophosphate compounds, are widely used in engines and APUs.

In some of the fume events flight crews have reported experiencing severe degradation in their mental capacity and performance, and only becoming aware of this after starting to use oxygen masks.

It appears that toxicological assessments at post mortem during accident investigations do not often include looking for signs of oil product ingestion. This raises the question as to whether cabin air contamination with oil products might insidiously have seriously impaired the crew, and consequently have been a significant causal factor in some apparently inexplicable accidents. Perhaps accident investigators have generally paid insufficient attention to this possibility?

2 Boeing 727, Flight DA1008, 25 April 1980, Tenerife, Canary Islands, Spain

A possible example: Boeing 727, Flight DA1008 – crash during a landing attempt at Tenerife Norte Airport in 1980. (Spanish Civil Aviation Accident Commission 1981).

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Review process: Editorial review. The corresponding author is marked with *.

The flight crew consisted of two pilots and a Flight Engineer. The Commander had an appreciable amount of flight experience. He had flown to Tenerife Norte 58 times, and the Co-Pilot 9 times. It is inescapable that the crew knew that there was serious high ground around the airport, with the 12,188 ft Mt Teide only a relatively short distance away. DA1008 descended towards the airport, navigating using radio beacons, probably mostly in cloud, intending to conduct a procedural approach based on an NDB (Non-Directional Beacon, a type of radio beacon). Deviations in airspeed, flight path, and position reporting, suggested crew performance may have been degraded.

The Air Traffic Controller (ATC) made a number of serious errors, including clearing DA1008 to descend to a dangerously low altitude, and unexpectedly instructing it to enter a holding pattern based on an NDB, using contradictory and confusing terms. The hold was unpublished, and therefore not on the crew's charts.

None of the crew members knew how to enter the hold. They discussed the matter for over 2 minutes, plainly showing they knew that they did not know, while wandering round to high ground. DA1008 was at 6,000 ft altitude, while in a sector with a minimum safe altitude of 14,500 ft.

The Ground Proximity Warning System (GPWS) activated. The crew applied full thrust, but did not level the wings, as specified by the procedure for a GPWS warning, and this seriously degraded the climb performance. The aircraft impacted the mountains, killing all on board.

3 Boeing 757, Flight AA965, 20 December 1995, Valle del Cauca, Colombia

A further possible example: A Boeing 757, Flight AA965, which crashed during a night landing approach to Cali, Columbia in 1995. (Aeronautica Civil of The Republic of Colombia 1996, Ladkin 1996).

The pilots were qualified and highly experienced and must have known of the mountainous terrain around Cali. Their inadvertent selection of an incorrect radio beacon caused a major departure of the aircraft from the intended flight path along a valley leading to the airport. On realising this, while knowing that they were uncertain about their position, the crew headed directly back towards the intended flight path. They did not seek assistance from ATC.

On approaching high ground, a GPWS warning triggered. The crew executed the escape manoeuvre, but omitted to retract airbrakes, severely degrading climb performance. The aircraft impacted the mountains, killing a number of the occupants.

4 Summary

In each of the above cases it is difficult to envisage how the experienced crew could have made the catastrophic errors that they did, unless they were impaired in some way. It appears possible that this could have been the result of ingesting oil products.

List of References

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About the Author

Tony Cable received his degree in aeronautical engineering from the University of London, United Kingdom.

He worked for Boeing and British Aerospace for a total of 9 years. As an Aircraft Accident Investigation Consultant, he served 32 years with the Air Accidents Investigation Branch (AAIB), investigating the engineering aspects of accidents and incidents to many types of fixed wing and rotary-wing aircraft with the aim of improving flight safety. These

include the crashes of Pan Am Flight 103 Boeing 747 at Lockerbie, the RAF Chinook on the Mull of Kintyre, and the Air France Concorde at Paris. He has been a Consultant on Engineering Failures for Accident and Failure Technical Analysis Ltd (AFTA) for around 15 years, chiefly in relation to major public transport accidents. He is an Aircraft Accident Investigation Lecturer and Visiting Fellow at Cranfield University and a licensed fixed-wing and helicopter pilot.

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ITF/ETF Perspective of Contaminated Air

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Abstract

Essentially the point of this paper is to express where the European Transport Workers' Federation (ETF) and the International Transport Workers' Federation (ITF) are and why we are supporting the campaign for clean aircraft cabin air.

Keywords

oil fumes, fume event, gas, disease, risk, organophosphates, aircrew, cabin, air, flight safety, aviation, industry

1 Coal Mines Used Canaries – Aircrew: Are They the Canaries of Today?

Canaries were once used in mines to detect odourless gas and being so small and little and frail they would die long before the level of gas became an issue for the miners[1] (Smithsonian Magazine 2016).

"Seals" is a play on words. Of course, it only works in English. I did check and find that in Spanish the word for a (mechanical) "seal" is not the same as the Spanish word for "seal" that live in the sea and flaps its flippers. A seal as we also know is a mechanical piece of equipment that restricts gases and liquids from moving through different parts of an engine or piece of mechanical engineering. The metaphorical reference to canaries and their crew just leads on to the word seal and why not juxtaposition the word between a mechanical seal and a living creature.

Evidence is compelling the evidence is strong we have people that work on aeroplanes becoming sick. Studies such as the Harvard project indicate that aircrew have a much increased risk of developing certain conditions and diseases than the general population (McNeely 2018, Harvard T.H. Chan 2018). Some of these conditions are also conditions that are linked to exposure to organophosphates and other chemicals found in oil operating at high temperatures.

[1] See also:
BEAUMONT, Bearnardine, 2019. *Tomb in the Sky – Aviation's Wounded Canaries*. London, UK: Bowker. Available from: https://www.amazon.com/dp/0993302548
LAFAYETTE, Porter, 2017. *Canary in the Cabin*. Available from: https://aviationtravelwriter.com/2017/04/02/canary-in-the-cabin/

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Review process: Editorial review. The corresponding author is marked with *.

Now we are not scientists or engineers or doctors this conference has many of those offering in-depth detailed chemistry, biology and physics. I am sure they will offer compelling evidence that will once again reaffirm the absolute need to dig deeper research, more redouble our efforts and not let Covid become a convenient blanket with which to cover this issue.

Not only are we aircrew, but we represent the aircrew. For us this is a really simple series of questions, does oil at very high temperature get in to cabin air through the bleed system? Does the oil that comes in to the cabin air system have a warning on the tin that says inhaling this product when used at high temperatures can lead to death? Are we seeing people with illnesses linked to those chemicals? Are we seeing people die with conditions linked to those warnings?

2 An Artificial Environment

Other than a few warning signs about keeping your seat belt fastened, not to smoke, turn your phone off and the odd sound of bells ringing there is very little and deliberately so to tell you exactly what aircraft is doing to keep you alive (**Figure 1**).

The truth is, we are in a completely artificial manufactured environment designed to keep a human being alive and make them feel comfortable (**Figure 2**). Even the lowest of the low cost outfits don't meddle with that.

But we must understand the extent to which the environment that we are working in is lethal to us. Only then can we imagine the complexity of the machinery that makes the environment one we can survive in.

Furthermore, we must also understand that most airlines operate the same aircraft. The industry is savage, competition is fierce, and margins are slim. Therefore, the rules and regulations that we flyby have to be not just minimum standards with no margin for the odd failure or slip.

As we have already heard, there are two distinct issues. One issue is the failure of a mechanical part and a fume event of a varying degree. The other issue is being exposed to low-dose burnt engine oil every single day, the cumulative effects of that over many years. The low-dose cumulative effect is what concerns us so deeply.



Figure 1: Air travel as we experience it.



Figure 2: Air travel as it is.

3 Dangerous Chemicals

Already the science of this campaign has taken us on a journey, and it has led to new revelation (**Figure 3**). We have found that there are certain people with certain DNA that will react worse than most. We will find more evidence that proves or goes beyond reasonable doubt – reasonable medical doubt – that the chemicals that aircrew are breathing in, day after day, after day are affecting their health.



Figure 3 Only a selection of presentations delivered by scientists at the Aircraft Cabin Air International Conference.

We have so many young women working in this industry at the point of which they are most likely to have children and they being exposed to these gases. No, I don't know whether or not it is because I work in an industry with lots of women that we hear of so many having issues and problems with pregnancy from miscarriages, stillbirths, inability to get pregnant and even losing babies? Or there is a problem that this industry is creating?

Depression and mental illness is commonplace in this industry. Now I know that we are as a society becoming more aware of mental illness, however, I am still seeing increasing numbers of people that need mental clinical help.

This is the 21st-century we do not need to risk other human being's health. Commercial aviation is a relatively new business; therefore we are only just seeing the long-term effects of being in this industry (**Figure 4**). We are only just having people have a 40 year career. We're only just seeing people in retirement developing illnesses in greater numbers. We have known that the chemicals that we are using are dangerous. The only question is by how much can we be exposed, really?

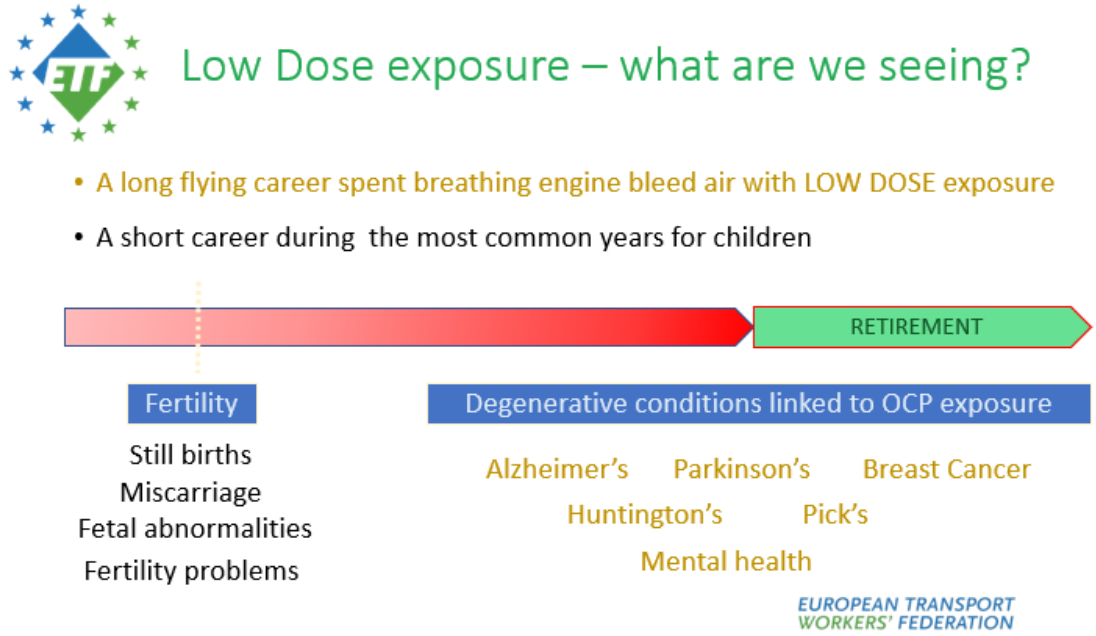


Figure 4: Long term effects of chemical exposure.

Are we looking at this properly? We know the chemicals when inhaled are dangerous. The only question is how much. And are there alternatives to not breathing in these chemicals? Yes, there are. History will judge the people that think they are very clever, very big, very wise, and the ones with all the excuses to say "no, we must carry on there is nothing to see here".

We have systems that prevent human beings from being exposed to these chemicals. There is no real reason on this planet to prevent applying these systems. What we suspect is that it is about lawyers, about litigation and cost which prevents these systems to be used.

4 Delays Again and Again

Look we all know that there are companies designing sensors and filters. We know that they can be retrofitted. We know that they will work.

Is it beyond reason that what is actually happening here is delay, the tactics of delay!

This is an industry issue not just an individual operator issue, whilst individual operators are faced with this. There isn't global proactive direction from the bodies as it should be. So, we will continue to see the industry do everything they can to push a solution of the problem into the future.

As a pragmatist you would say: How can we confirm there is a problem? And: Do we have a solution? This is a multibillion dollar industry. Can we conceivably stop people flying, if there is a problem and we do not have a solution? Well, yes, we just have – look what has happened with Covid.

I feel that industry and regulators are employing drag anchors to slow down a solution. The application of sensors and filters seem like an opportunity to make this a historical issue only. The future is safe and we can hand this over to scientists and lawyers to thrash this out for years to come. And whilst that might seem preferable particularly because fume events might be rarer and therefore not as many passengers will be affected – it doesn't fully resolve the problem of low dose, continual exposure. The crew again are Canaries being exposed to fumes until the science can catch up and be accepted as damaging to our health.

Every day we delay, more aircraft roll off the production line with bleed air systems. Each aircraft means 20 years or more to contaminate aircrew just beginning their careers.

Cost aside, there is little reason for doing anything other than changing the cabin air we breathe by changing how it is provided onboard.

5 Conclusion

With the evidence we have seen over the years, it is difficult to suggest we as ETF and the ITF shouldn't be supporting this campaign for clean cabin air with everything we have.

I have been flying for over 22 years – I hear an awful lot of counter evidence based on a lack of science, or inconclusive data, or new research instigated by industry, or regulators have not detected anything we should worry about.

In 22 years and my position that puts me in contact with crew all over the world, I have not heard a single crew member tell that they have been involved in any major study aimed at looking at their health relating to this topic from any source other than by unions and groups worried about the effects of cabin air quality. I am not suggesting that industry has not undertaken serious studies, only that the data I have seen presented by the concerned groups is far more compelling and comprehensive.

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Advanced Technology Filtration For A Better Crew And Passenger Experience

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Abstract

Cabin air on commercial aircraft today is typically supplied by bleed air systems from engines or APU's or ram air. This input air contains contamination, which may include hydraulic fluids, engine oils, pyrolysis products, multiple types of volatile organic compounds (VOC's), ozone and particulates. For the safety and well-being of crews and passengers, removal of these type of these contaminants as well as odors from bleed air and/or re-circulated air is essential to improve cabin air quality. Thinking of air quality as a matter of safety, as opposed to simply comfort, has dramatically changed the way that airlines make decisions regarding the products and services used to attain clean air in the cabin of the aircraft. This is even more important today as we work to provide a safe cabin environment to remove bacteria and viruses. Airlines, OEM's and the traveling public are just now starting to realize how important cabin air quality is to the aviation industry. PTI Technologies has been investing in advanced designs and new technology to meet this need, and has been testing this against existing industry standards. Our presentation will share the results of this work and how it can positively impact the commercial aviation industry by providing quality cabin air for a better crew and passenger experience.

Keywords

PTI, PTI Technologies, cabin air, bleed air, contamination, VOC, particulates, ozone, safety, cabin, environment

1 Introduction

The cabin air on commercial aircraft today is typically supplied by two sources – 50% from recirculated air and 50% by bleed air taken from the compressor section of the engines or APU's. The one exception today is the 787, which uses compressed ram air. The 50% of the cabin air that comes from the bleed air contains contamination, which may include hydraulic fluids, engine oils, pyrolysis products, multiple types of volatile organic compounds and particulates, as well as ozone. For the health, safety and well-being of crews and passengers, removal of these type of contaminants

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as well as odors from bleed air and/or re-circulated air is essential to improve cabin air quality. Thinking of air quality as a matter of flight safety and health, as opposed to simply comfort, has dramatically changed the way that airlines make decisions regarding the products and services used to attain clean air in the cabin of the aircraft. This is even more important today as we work to provide a safe cabin environment to remove bacteria and viruses. Airlines, OEM's, regulators and the traveling public are just now starting to realize how important cabin air quality is to the aviation industry.

PTI first successfully applied cabin air filtration technology in 1989 on the B-2 program, and this has continued in a number of other military and manned space programs. During this time, PTI's engineering team has invested in the development of special filter media by collaborating with media companies to meet our customer's challenging requirements and specifications. These applications required custom IP adsorbents to capture gases such as:

- Ammonia
- Phenol
- Indole
- Skatole
- Butyric acid
- Methyl Mercaptan
- Hydrogen Sulphide

PTI's development of cabin air filters for military program has required development of special custom adsorbents to capture Chemical War Agents (CWA) to protect cabin air including:

- VX gas
- Soman gas
- Mustard gas

PTI's integration of advanced integrated HEPA technology with adsorbents impregnated proprietary media technology is used today to meet performance requirements of military and manned space cabin air filtration applications. In addition, PTI's newest CabinSafe® HEPA technology has been in service since 2012 with global airlines for the recirculation air loop on a number of Boeing and Airbus commercial aircraft. For bleed air applications, PTI has designed, manufactured and supported APU bleed air removing liquids and particulates on a number of engine applications for P&W, Honeywell, Lockheed, Rolls-Royce, Airbus, Embraer and military customers.

Over the last few years based on customer inputs, PTI Technologies began investing in advanced filter designs and new technology to meet customer needs in providing a higher level of filtration for Fuel Tank Inerting Systems (FTIS) to extend the life of the air separation modules. PTI engineering team has now developed patented integrated FTIS filtration designs, which offer improved performance in capturing aerosols (liquid and particulates), Volatile Organic Compounds (VOC's) and other contaminants as well as providing ozone conversion. PTI has manufactured these FTIS filter designs and tested them in-house and at independent third party laboratories to EN and ISO standards and the results, show significant promise for improved filtration performance as discussed below. During this technology development and test programs, PTI also began to understand that this technology was directly applicable to the challenge of filtering the bleed air portion of aircraft cabin air.

This technical paper will show PTI's design approach and results of our work on this integrated filtration technology and how it can positively impact the commercial aviation industry by providing quality cabin air for a safer and more healthy environment in the aircraft as well as a better crew and passenger experience. This paper will also focus on how cabin air filters affect the quality of cabin air and how air filters can be used to limit crew and passenger exposure to aerosols, VOC's, contaminants and ozone. It will also cover filter efficiency and explain why PTI is recommending certain levels of filtration to achieve optimum results.

2 Background

Aircraft cabin air quality and safety has never been under such a strong public focus as it is today, during the COVID-19 pandemic, especially given strong evidence that these viruses can spread as aerosols through the air. However, in reality, the subject of aircraft cabin air quality has been a topic of discussion in the industry since the 1950's when Boeing first recognized the need for filtration, but did not have the filtration technology to answer the problem. Although we have evolved technology and slowly brought HEPA filtration to commercial aircraft today, it has only been a partial answer. Within the industry, there have been a number of issues and incidents where cabin air quality has affected the health of crew, flight safety from the incapacitation of crew, as well as negative effects on passengers.

In doing design of filters to address cabin air quality, there are many factors to consider. Aerosols are so small that buoyant forces overcome gravity, allowing them to say suspended in the air for long periods, or they evaporate before they hit the floor, leaving the solid particulate ("droplet nuclei") free to float very long distances, causing what we often refer to as "airborne" transmission. There is growing evidence that in addition to contact and droplet spread, the transmission of aerosols is plausible under favorable conditions, particularly in relatively confined settings with poor ventilation and long duration exposure to high concentrations of aerosols. As we address viruses, the virus may attach to smaller or larger particles (solid or liquid), so a wide range of particle sizes have to be considered from some micrometers down to the nanoscale. PTI's advanced filter technology was developed to remove aerosols and virus carrying particles to improve cabin air quality.

Bleed air is outside air and in theory it should be fresh and clean. However as it passes through the compressor section of the engines or APU, it becomes contaminated with aerosol droplets or vapors of engine oil, hydraulic fluids, other organic or inorganic compounds, carbon dioxide or other by-products of combustion as they enter the aircraft. The recirculated portion of cabin air is not fresh and given the potentially large numbers of passengers on an aircraft, there are high concentrations of particulates. These particulates include fibers, dust, skin particles, bacteria (up to 30,000 bacterial organisms per minute per passenger could be released into the cabin environment), as well as odors in the air inside an aircraft. Bacteria thrive in high humidity, and viruses thrive in low humidity - both conditions can be found on commercial aircraft. All of these contaminants are all a potential risk to crews and passengers.

If we think of cabin air quality as a matter of flight safety and health, as opposed to simply passenger comfort, it dramatically changes the way that consumers make decisions regarding the products and services used to attain clean air. Using an air filter with a higher Minimum Efficiency Reporting Value (MERV) rating than what a system is designed for, can actually impair its performance. The smaller pores in more highly rated air filters create resistance to air flow, can lower the system's efficiency and put strain on the overall system.

Cabin air contamination comes in two different forms:

1. **Solid particulates** (dust, pollen, smoke particles, dust mites). HEPA filters are used to filter solid particulates out mechanically.
2. **Gaseous air pollutants** (odors, smells, VOCs, cigarette smoke smell, kitchen oil smell, etc.). The job of removing this falls on the activated adsorbent portion of an air filter.

The combination of HEPA filters and activated adsorbent filters working in tandem is needed to solve the complex problem of cabin air quality - they are the two most important air purifier filters.

Odors, smells, and Volatile Organic Compounds (VOC's) just pass through HEPA filter media as they are gases - a mechanical barrier does not stop them. Rather, a process of adsorption to an activated adsorbent material stops them. During the adsorption process, the gas molecules adhere to a solid surface of adsorbents. PTI filters technology addresses this issue by using advanced integrated HEPA technology, which integrates HEPA filters with adsorbent impregnated proprietary media technology.

3 PTI Advanced Integrated HEPA Technology

PTI's current in-service cabin air filters are High Efficiency Particulate Air (HEPA) filters and are manufactured using recommended practices as published in Environmental Technologies, not ASHRAE.

PTI advanced integrated HEPA technology filters improves air quality by adding new technology to reduce VOC's, minimizing adverse health effects such as headaches, nausea and nose/throat irritation or discomfort. Our integrated HEPA technology filters also reduce severe odor incidents thereby reducing unscheduled maintenance and repairs and keeping flights on schedule. These filters were developed with extensive work conducted by PTI's Engineering team in partnership with media manufacturers and OEM's. Tests conducted by independent labs have shown that CabinSafe® advanced integrated HEPA filters with ozone catalytic converters can reduce VOC's and ozone concentrations in the cabin thus keeping a healthy cabin air quality for the crew and passengers. These filters are engineered with a multi-layer media enabling to trap the dirt and large particles before the air reaches the final filters downstream, which then remove the smaller particles. This multi-filter system extends the life of the filters, leading to overall cost savings. PTI advanced integrated HEPA technology filters can perform better for same basis weight and pressure drop as other filters in the market.

3.1 Performance Test Data For Integrated Filter Elements

PTI advanced integrated HEPA technology filters were tested per EN 4618. **Figure 1** shows the aerosol (liquids and particulates) efficiency versus particle size.

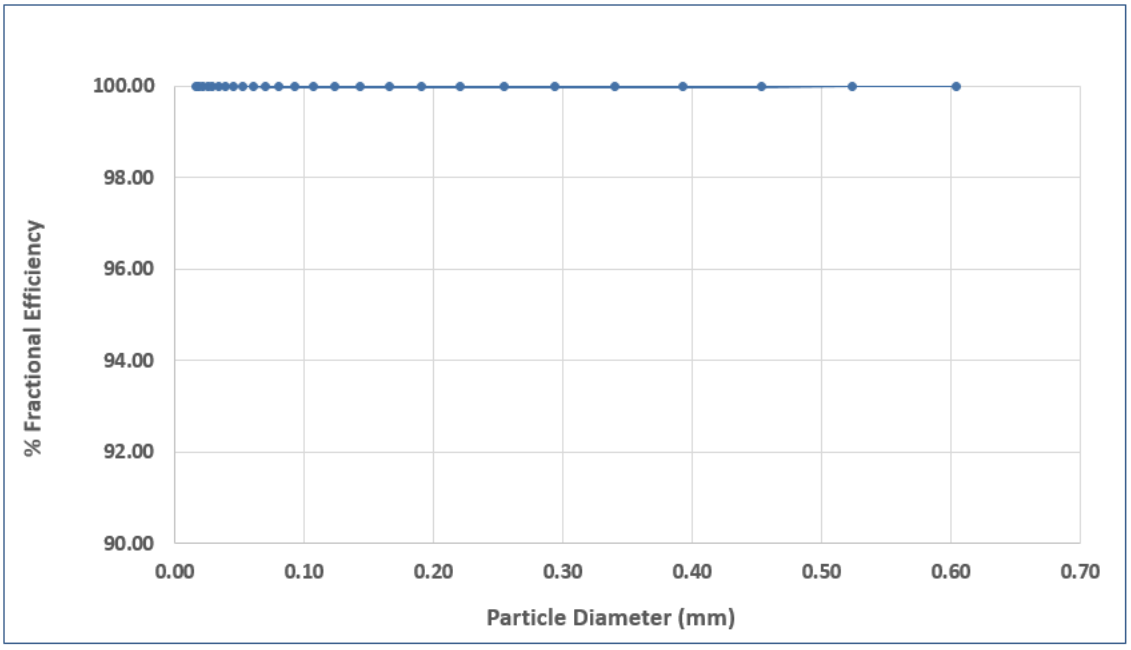


Figure 1 Aerosol efficiency versus particle diameter.

The filter element was then tested against single challenge gases per EN 4618. The first challenge gas was formaldehyde:

- Air Flow Rate: 45.75 cfm (3.5 lbs/min)
- Upstream Concentration: 38 ppb
- Temperature: 160 °F (71 °C)

The results of this testing are show in **Figure 2**.

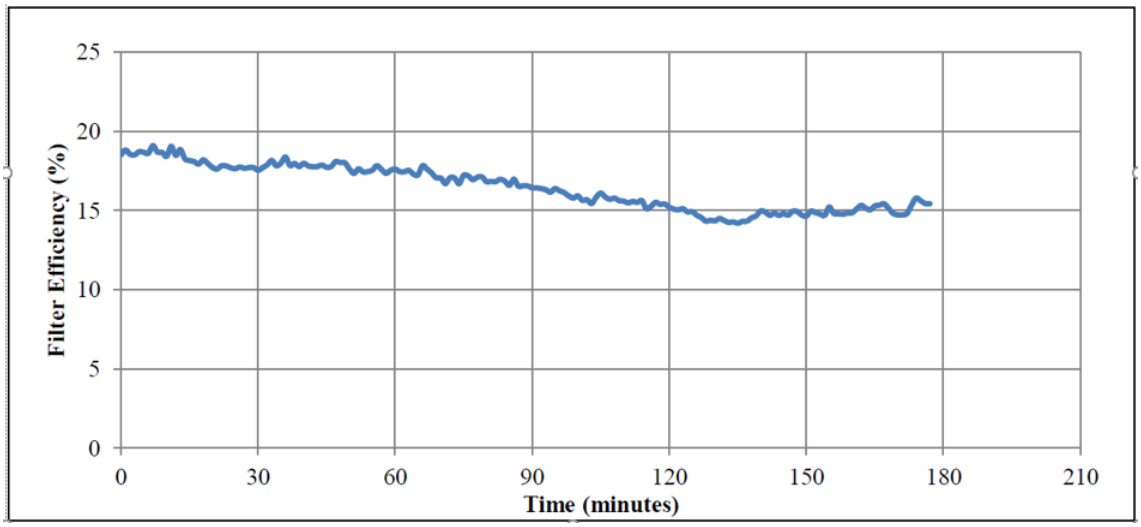


Figure 2 Adsorption curve: Efficiency versus time.

PTI's integrated filter element was also subjected to ozone testing to determine performance of the new catalytic converter technology being used. This test was to determine both efficiency of the converter and performance at various temperatures. The test was performed at:

- Air Flow Rate: 58.8 cfm (4.5 lbs/min)
- Upstream Concentration: 9.5 ppm
- Temperature: 160 °F (71 °C)

The results of these tests are shown in **Figure 3** and **Figure 4**.

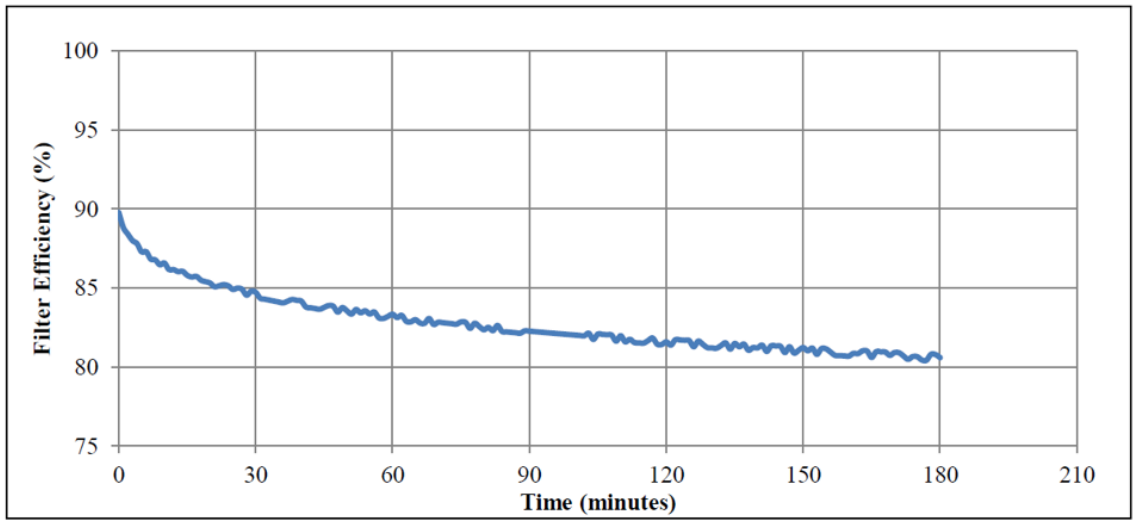


Figure 3 Adsorption curve: Efficiency versus time.

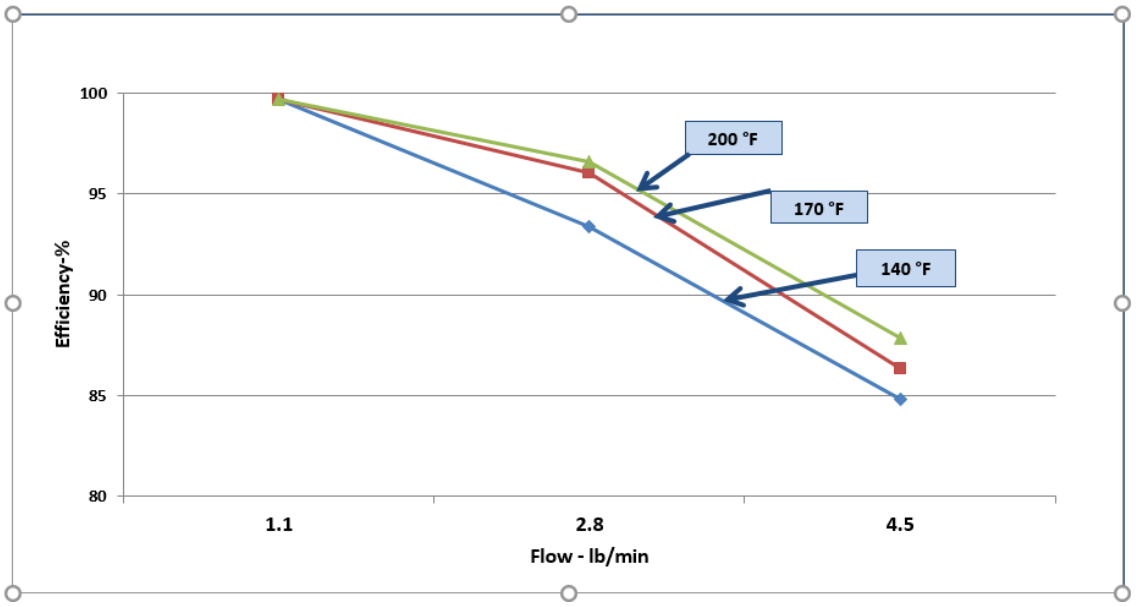


Figure 4 Efficiency versus temperature.

The filter element was tested against a mix of five challenge gases per EN 4618. The gas mixture was Butane, Formaldehyde, Naphthalene, Toluene and Ozone. The test conditions were:

- Air Flow Rate: 45.75 cfm (3.5 lbs/min)
- Upstream Concentration: 13 ppm
- Temperature: 72.3 °F (22.4 °C)

The test results are shown in **Figure 5**.

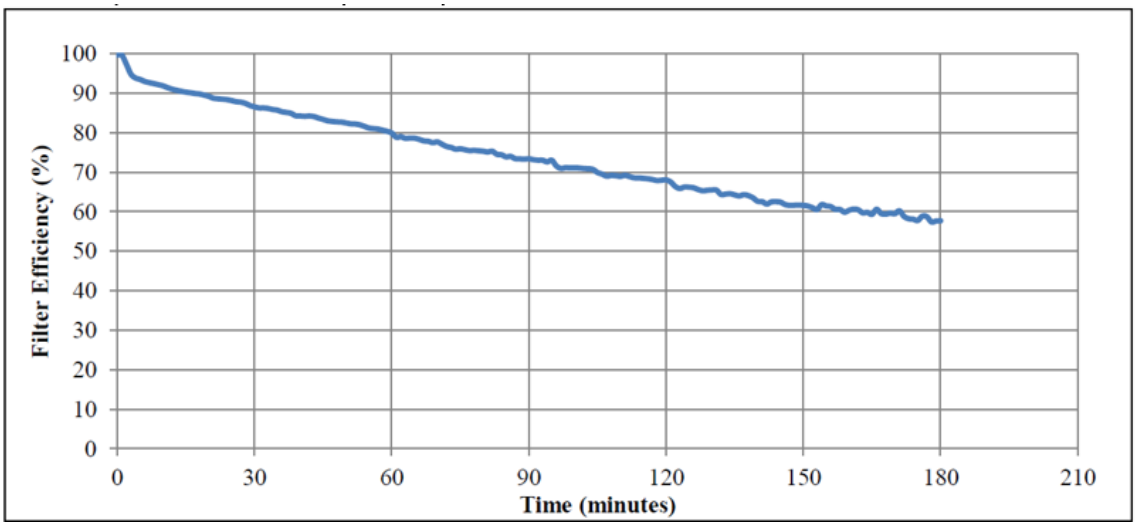


Figure 5 Adsorption curve: Efficiency versus time.

4 Conclusions

- PTI offers advanced HEPA filter technology best integrated solution for the removal of aerosol, air particulates and VOC reduction including ozone.

- PTI's Integrated Filter Modular Design
    1. Used as a cabin air filter will eliminate adverse health effects for crew and passengers, or if used in a FTIS application, increase protection for the Air Separation Module (ASM).
    2. Provides low pressure drop.
    3. Keeps energy costs low and can be easily adapted for use in existing air systems.
    4. Lightweight and long life.
    5. Ensures economical operating costs.

About the Authors

Kanwar Suri holds a MS (Engineering) and DER FAA certification for PTI Technologies. He is the Senior Vice President of Engineering with over 35 years' experience in hydraulic and filtration industry. He was a chairman of Vice Chairman of SAE Contamination Committee and Secretary of NFPA Committee. He is actively involved in several SAE & NFPA technical committees and guides them to develop industry standards, has written and presented technical papers to INDA and FILTECH filtration conferences and holds several US patents in the field of hydraulic filtration and pressure sensing devices.

Michael Gao received his B.E. and M.E. degree in Mechanical Engineering from Zhejiang University, Hangzhou, People's Republic of China in 1989 and M.S. degree in Engineering Mathematics from Claremont Graduate University, Claremont, California in 1996. From 1996 to 2000, he was a Design Engineer; Project Engineer with Western Filter Corp. (now Donaldson). Since 2001, he has been a Sr. Design Engineer, Sr. Project Engineer, Engineering Manager and the current position of Director of Engineering with PTI Technologies Inc. He is a voting committee member of SAE A-6C1 Contamination & Filtration Group, SAE AE-5D Fuel Tank Flammability Reduction Systems Group and has authored numerous SAE documents for publications. Mr. Gao holds four US Patents and is an expert in the aerospace filtration industry.

David Conrad received the B.S. degree in Chemical and Petroleum Refining Engineering from the Colorado School of Mines, Golden, Colorado in 1979. Currently, he is the Vice President, Business Development at PTI Technologies based in Oxnard, California. Before joining PTI, he was with Zodiac Water & Waste Aero Systems as Vice President, Sales Marketing and Customer Service. He spent three years as the Director International Sales & Marketing of Guangzhou Aircraft Maintenance and Engineering Co., Ltd (GAMECO) in Guangzhou, People's Republic of China. He has also served as the Vice President, Sales, Marketing and Customer Service as well as General Manager, PSI at Rexnord Aerospace, as well as positions with Goodrich Cargo Systems (based in Beijing, China), and AeroUnion Corporation. He began his career progressing through a number of business development and leadership positions in Honeywell/ AlliedSignal. Mr. Conrad holds one US Patent.

PTI Technologies Inc.



Advanced Technology Filtration for a Better Crew and Passenger Experience

David Conrad

Aircraft Cabin Air International Conference 2021
18 March 2021

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Situation And Need – Our View

- Aircraft cabin air comes from two sources
  - 50% - “Fresh” Air (bleed air from engine / APU compressor section)
    - Exception is 787 – ram air
  - 50% - Recirculated Air from cabin
- The Recirculated Air is treated today – HEPA Filters
  - Removes particulates, viruses, bacteria, fungus
  - Does not handle gases/odors – need second media (activated carbon)
- However, “Fresh” Air really has no treatment except Ozone
- The “Fresh” Air component is the driver of air quality
  - Contains aerosols, VOC’s, particulates and ozone
  - Creates health/safety issues for flight crew
  - Degrades passenger experience
  - No filtration/removal and low ozone conversion at lower temperatures

An Effective Solution For Bleed Air Filtration Is Needed

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Potential VOC's In Engine Bleed Air

1,1,1-trichloroethane
1,1,2,2-tetrachloroethane
1,1,2-trichloro-1,2,2-trifluoroethane (Freon-113)
1,1,2-trichloroethane
1,1-dichloroethane
1,1-dichloroethene
1,2,4-trichlorobenzene
1,2,4-trimethylbenzene
1,2-dibromoethane
1,2-dichlorobenzene
1,2-dichloroethane
1,2-dichloropropane
1,2-dichlorotetrafluoroethane (Freon-114)
1,3,5-trimethylbenzene
1,3-butadiene
1,3-dichlorobenzene
1,4-dichlorobenzene
1,4-dioxane
2,2,4-trimethylpentane
2,3-dimethylpentane
2-butanone (methyl ethyl ketone)
2-hexanone (methyl butyl ketone)
3-Methylhexane
4,4'methylene bis(o-chloroaniline)
4-ethyl toluene
6methyl5heptene2one
acenaphthene
acetaldehyde ←
acetone ←
acrolein ←
AHTN
anthracene
benzene ←
benzo(a)anthracene
benzo(a)pyrene ←
benzo(b)fluoranthene
benzo(e)pyrene
benzo(ghi)perylene
benzo(k)fluoranthene
benzyl acetate
benzyl chloride
biphenyl
bromodichloromethane
bromoform (tribromomethane)
butyl benzyl phthalate
carbon disulfide
carbon tetrachloride (tetrachloromethane)
chlorobenzene
chloroform (trichloromethane)
chrysene
cis-1,2-dichloroethene
cis-1,3-dichloropropene
cis-permethrin
cyclohexane
decanal
di-2-ethyl hexyl phthalate
dibenzo (a,h)anthracene
dibromochloromethane
dibutyl phthalate
dichlorodifluoromethane (Freon-12)
diethyl phthalate
ethanol ←
ethyl acetate
ethyl chloride (chloroethane)
ethylbenzene
fluoranthene
fluorene
formaldehyde ←
heptane
hexachloro-1,3-butadiene
hexane
hexyl cinnemal
HHCB
Indeno(1,2,3-cd)pyrene
isoprene (2-methyl-1,3-butadiene)
isopropyl alcohol
limonene
m&p-xylene
methyl bromide (bromomethane)
methyl chloride (chloromethane)
methyl isobutyl ketone (4-methyl-2-pentanone)
methyl methacrylate
methyl tert-butyl ether
methylcyclohexane
methylene chloride (dichloromethane) ←
naphthalene ←
nonanal
octanal
o-xylene
PCB 11
PCB 52
phenanthrene
phenethyl alcohol
propene
propionaldehyde
Pyrene
styrene
Sumithrin
tetrachloroethene
tetrahydrofuran
toluene
trans-1,2-dichloroethene
trans-1,3-dichloropropene
trans-Permethrin
trichloroethene
trichlorofluoromethane (Freon 11)
tri-m,m,p-cresyl phosphate
tri-m,p,p-cresyl phosphate
tri-m-cresyl phosphate
tri-o-cresyl phosphate ←
tri-p-cresyl phosphate
tris(2-chloroethyl)phosphate
tris(dichloro)phosphate
vinyl acetate
vinyl chloride (chloroethene)

Many Potential VOC's In Bleed Air – Complex Problem To Remove All

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Situation And Need – Our View

- What are the challenges for effective solution for Bleed Air?
  - Which VOC's to remove – which possible ones to choose?
  - How to best remove aerosols (liquids, particulates)?
  - How to get better ozone conversion - especially at low temperatures?
  - Packaging filter for aircraft (footprint, weight, certification, life)?
  - How to make installation easy (new, existing)?
  - How to make cost effective to install, operate and maintenance?
- Fortunately, there is a solution
  - New technology for bleed air in Fuel Tank Inerting Systems (FTIS)
  - Simple design, lower weight, long life, economical costs
  - Handles aerosols, VOC's, and ozone in a single envelope
  - Combined with recirc filters – better cabin air quality
- Filter design tested – ready to fit to aircraft, working with partners

Technology Now Tested And In Hand For Bleed Air Solution

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What's At Stake

- Our industry – flight crews
  - Contaminated air has impaired and incapacitated flight / cabin crew
- Our industry – passengers
  - Exposure to chemicals, fumes and ozone – public health risk
- Our industry - manufacturers
  - Idea of filtration now new – considered since 1950's but lack of solutions
- Air Accident Investigators globally and Law Courts
  - Contaminated air exposure - risk to flight safety, crew and public health
  - Understanding of chemicals present during these exposure events
  - Increased financial and legal liability
  - Call on regulators / Governments to mandate effective "bleed air" filters and contaminated air warning sensors on passenger aircraft

Call To Action – Solutions Needed For Crew And Passengers

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PTI's Pedigree In Air Filtration

- Who is PTI Technologies
  - World leader in aviation/aerospace filtration for over 60 years
  - Filtration for all aircraft fluids – hydraulics, air/bleed air, fuel, water, lube
- Our experience and pedigree in air filtration
  - We have supplied air filtration for military aircraft since the 1980's
    - Special media developed to capture dangerous gases/chemicals/particulates
  - Continued development for military today – cabin air and breathing air
  - Developed / certified of air filtration for Space Launch System (gases)
  - Developed / certified / in-service HEPA Cabin Air Filters for airlines
  - Developed / certified / in-service engine / APU bleed air filtration
  - Developed / tested filtration combined with custom absorbents
  - Developed / tested patented FTIS filtration (Aerosols, VOC's, HEPA, Ozone)

PTI Has Pedigree And Technology For Bleed Air Solution

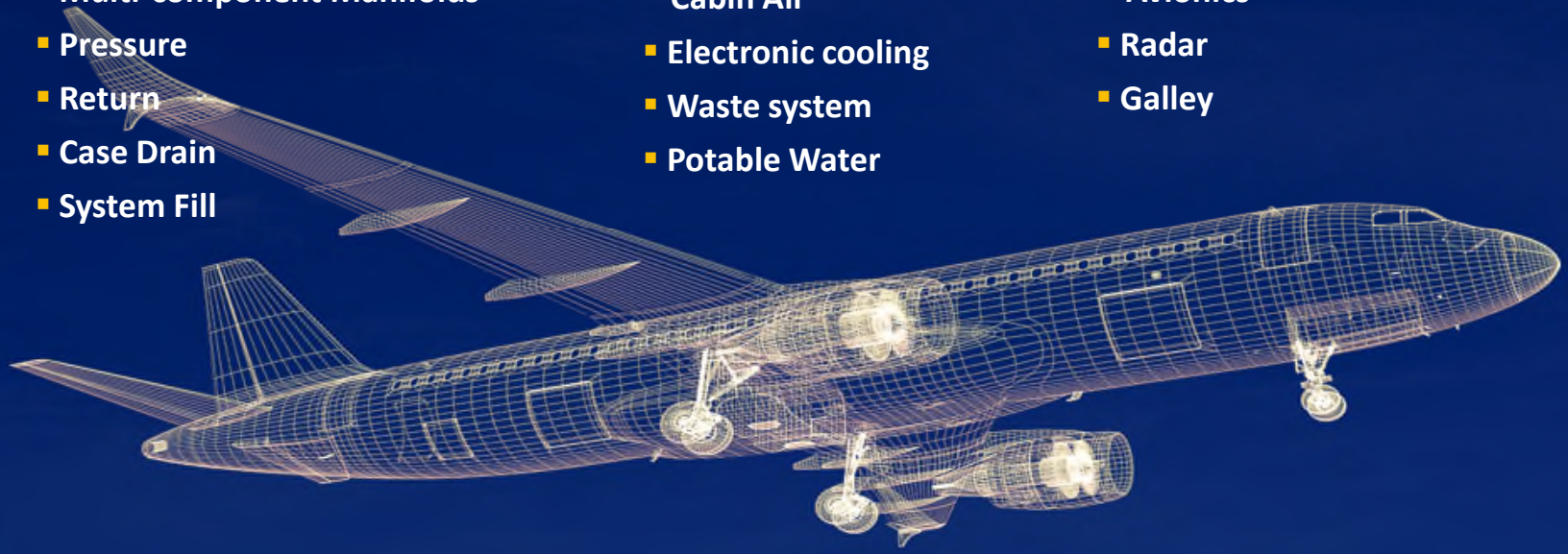
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Aerospace Product Applications

Main Hydraulic Systems
- Multi-component Manifolds
- Pressure
- Return
- Case Drain
- System Fill

Environmental
- Cabin Air
- Electronic cooling
- Waste system
- Potable Water

Liquid Cooling Systems
- Avionics
- Radar
- Galley



Engine Filtration
- Fuel
- Main Lube
- Scavenge Lube
- Bleed Air

Electric Systems
- IDG Lube
- CSD Scavenge

Flight Control Filtration
- Rudder Control
- Elevators
- Ailerons
- Ground Spoilers
- Thrust Reversers

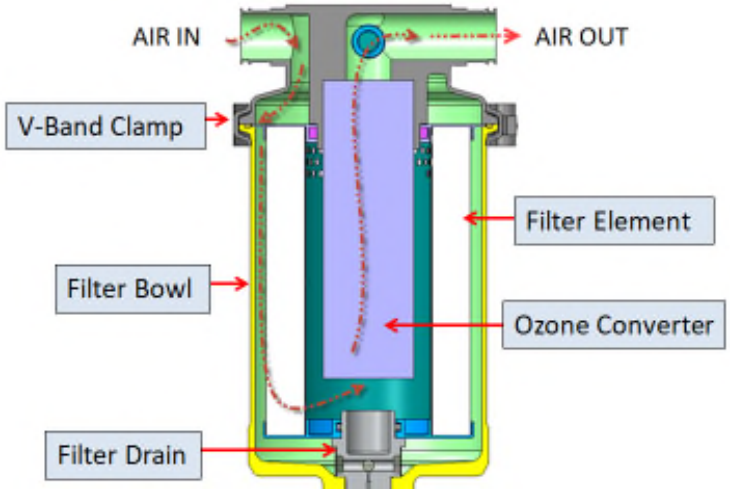
Auxiliary Power Unit
- Fuel
- Lube
- Bleed Air

Company Private – © PTI Technologies 2019

PTI's Solution To Bleed Air Filtration

- Solution – Advanced Technology Filtration developed for FTIS
  - Removes Aerosols (Liquids, Particulates), Gases/VOC's, Ozone + HEPA
  - Incorporates multilayer media, active absorbent and ozone conversion
  - Proven patented technology and designs
- Tested to EN / ISO Standards
  - Aerosols (Liquids, Particulates)
  - Challenge Gases – single and mixed
  - Ozone conversion





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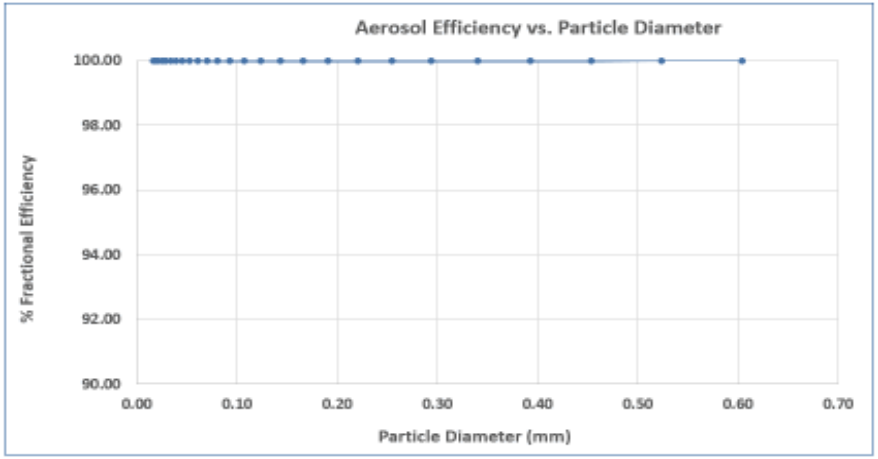
Bleed Air Filtration Testing – EN4618-2009

Category	Group	Compound	CAS No.	Bio-effluents	Cabin Interior	Solvents	External Conditions	Exhaust	Oils, Lubricants & Hydraulics	Fuel
Inorganic Compounds		Carbon Dioxide	124-38-9	☒			☒ [a]	☒ [a]		
		Carbon Monoxide [a]	630-08-0				☒	☒	☒	
		Nitrogen Oxides [b]	10102-44-0				☒	☒		
		Ozone [a]	10028-15-6				☒			
Inorganic / Organic Particles		Particles, aerosols		☒ [a]	☒ [a, c]		☒	☒	☒	☒
		Micro-organisms		☒ [a]	☒ [a]		☒			
		Endotoxins		☒ [a]	☒ [a]		☒			
Aliphatic Compounds	Alkanes	Methane [b]	74-82-8	☒				☒		☒
	Ketones	Acetone [a]	67-64-1	[d]		☒			☒	
		Methyl Ethyl Ketone [a]	78-93-3			☒			☒	
	Aldehydes	Acetaldehyde [a]	75-07-0					☒	☒	☒
		Acrolein [a]	107-02-8					☒	☒	☒
		Formaldehyde [a]	50-00-0		☒ [e]	☒		☒	☒	☒
	Halogen Derivatives	Methylene Chloride [a]	74-87-3			☒			☒	
Aromatic Compounds		Benzene [a]	71-43-2					☒		☒
		Tricresyl Phosphate [b]	1330-78-5						☒	
		Toluene	108-88-3			☒ [a]		☒	☒	☒
Polycyclic Aromatic Hydrocarbons		Benzo (alpha) Pyrene [b]	50-32-8					☒		☒
		Naphthalene [b]	91-20-3					☒	☒	☒

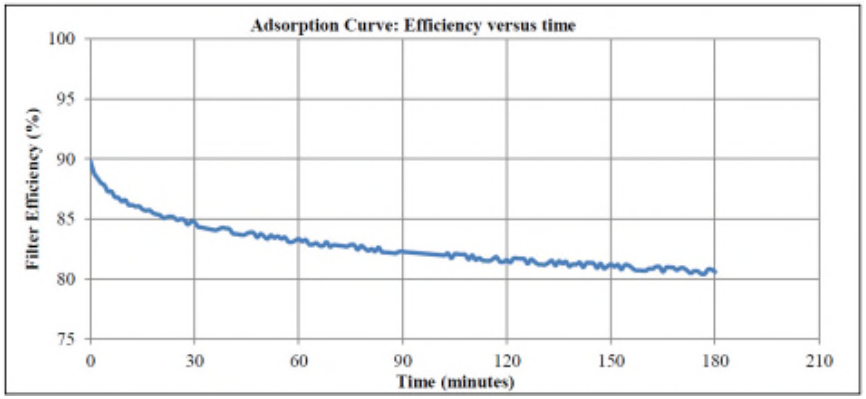
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Testing Results

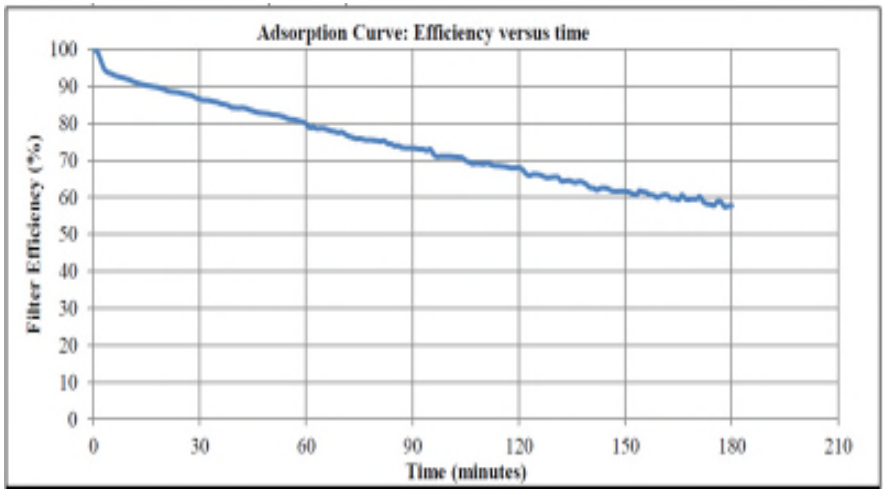
AEROSOLS (fine solid particles / liquid droplets)

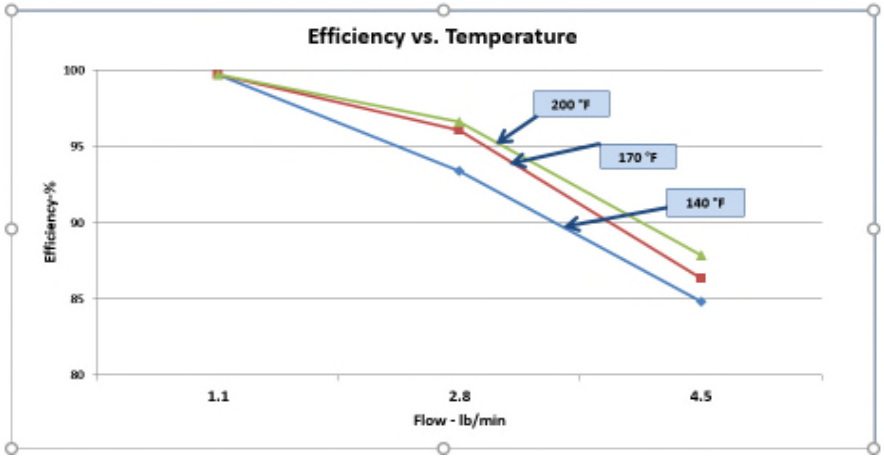


OZONE



GAS ADSORPTION





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What's Next

- Next step is to bring bleed air filtration in-service to airlines
  - Specifications (bleed air, filtration) to optimize design / performance
  - Prototypes / flight test program
  - Certification – STC and / or OEM
  - Retrofits / new production
- Need airline partners - collaborate on design/installation/test
- Need OEM support for simple solution
  - Certify across platforms
  - Create aftermarket support – documentation, manuals

Technology Is In Hand To Address The Bleed Air Filtration Need

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For More Information / Partnering

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Editors: Dieter Scholz, Susan Michaelis

AIRCRAFT CABIN AIR
International Conference 2021

Patching up Risks? – A View on Human Factors and Toxic Fumes

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Extended Abstract

Historically aviation is known for improving and enhancing the design of aircraft, from the 1980's Ground Proximity Warning System (GPWS) until today's advanced automation with reduced separation allowing for more traffic. Sometimes however, the system behaves in ways that the designers did not think of – an example of this is the B737 MAX, or an oil leak affecting the air quality and the people working onboard an aircraft. Very often the design is finished by the most adaptive element in a system – the people, and we may not even notice that the design was flawed in the first place.

But what assumptions lie around risk, when we talk about toxic fumes in the aircraft? Diane Vaughan (1986, p. 62) tells us that "Risk is in the eye of the beholder" and it seems that the risk associated with toxic fumes depends on the eyes looking at it. From a regulatory point, there seems to be different views on the risk associated with toxic fumes. While ICAO (2015, p. 1) states: "… particular concerns have been raised regarding the negative impact on flight safety when crew members are exposed to oil or hydraulic fluid fumes or smoke and experience acute symptoms in flight", EASA 2017 seems to come from a different perspective: "Contaminated air is not a flight safety issue. The air quality on a passenger jet aircraft is similar or better than what is observed in normal indoor environments".

Yet, an increase in reports of smell, smoke and fumes have increased over the last five years (AAIB 2020) and from investigating numerous fume events, common features have been identified. These common features suggest a systemic design flaw not presently accounted for, and for the people involved this emergent system property changes the risk profile.

Humans adapt to make things work. Most of the time things go well, because humans in the system are fantastic, through their ability to adapt and adjust their performance to patch up systems imperfections and messy details that seems to go beyond the designs in the system, in ultimately sustaining the daily operation. But this adaptability is finite (Woods 2015) and susceptible to outer factors influencing. Humans make an enormous contribution to safety, but certain designs in work structures, equipment and tools needs to be in place for the sharp end people to do their job in a safety critical environment.

Checklist serves to aid the pilots as simplified means in abnormal situations, like a toxic fume event. Toxic fumes are often not associated with smoke but smell, and often appear suddenly with rapid effect on the crew. The design of

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Related presentation: https://doi.org/10.5281/zenodo.5515399
Review process: Editorial review.

some checklist in regards to smoke/fumes therefore seems to be incomplete as these are "geared towards identification and isolation of any possible source of smoke in the airplane. Therefore it is not suited to determine and eliminate the various causes of smell" (BFU 2015).

From AAI Bulletin (AAIB 2000) an example of how the pilots patch up the deficiencies of the system seems to rely on their previous experience. The report states that both pilots had been exposed to toxic fumes before, which they had discussed the evening before. "The flight crew's previous experience suggested that if the smell was going to re-occur, it was most likely to occur when thrust was reduced for descent, so during the cruise they discussed their actions if the smell returned and reviewed the SMOKE/FUMES/AVNCS Checklist" (AAIB 2020, p. 2). One may ask whether we can rely on sufficient experience being present on the flight deck to prevent harm? And whether this responsibility should be placed in the hands of the pilots?

What perhaps seems to go unrecognized is how people are the most adaptable element in a complex work system, and what this means to the wider system – like systems safety. "People are the most adaptable element in any complex work system. This adaptability is essential in making things work, both in ordinary but especially in extraordinary circumstances" (Wears 2013, p. 338). Safety is not something we have, safety is something we do, and dependent upon the adaptive capacity present. One may wonder, are we willing to trade this adaptive capacity and ignore the signals of risk from the sharp end people, research and investigations, at the expense of safety and employee's health and well being?

This text suggests that design improvement is required, in order not to jeopardize the health and well-being of the employees. "Users should not have to adapt to support systems, rather systems should adapt to support users" (Wears 2013, p. 1).

Keywords

risk, human factors, fume event, toxic fumes, flight safety, health, adaptability

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About the Author

Gitte Furdal Damm is a former captain on the ATR 72-600 and has been working at various Danish Airlines such as Cimber Air and Jettime. Since 2015 she has been a CRM Trainer and is the owner of About Human Factors, which provides CRM courses in aviation. She is currently also attending the MSc program in Human Factors and System Safety at Lund University.



Gitte Furdal Damm

Patching up Risks?
A View on Human Factors and Toxic Fumes

Aircraft Cabin Air Conference, March 15th - 18th 2021

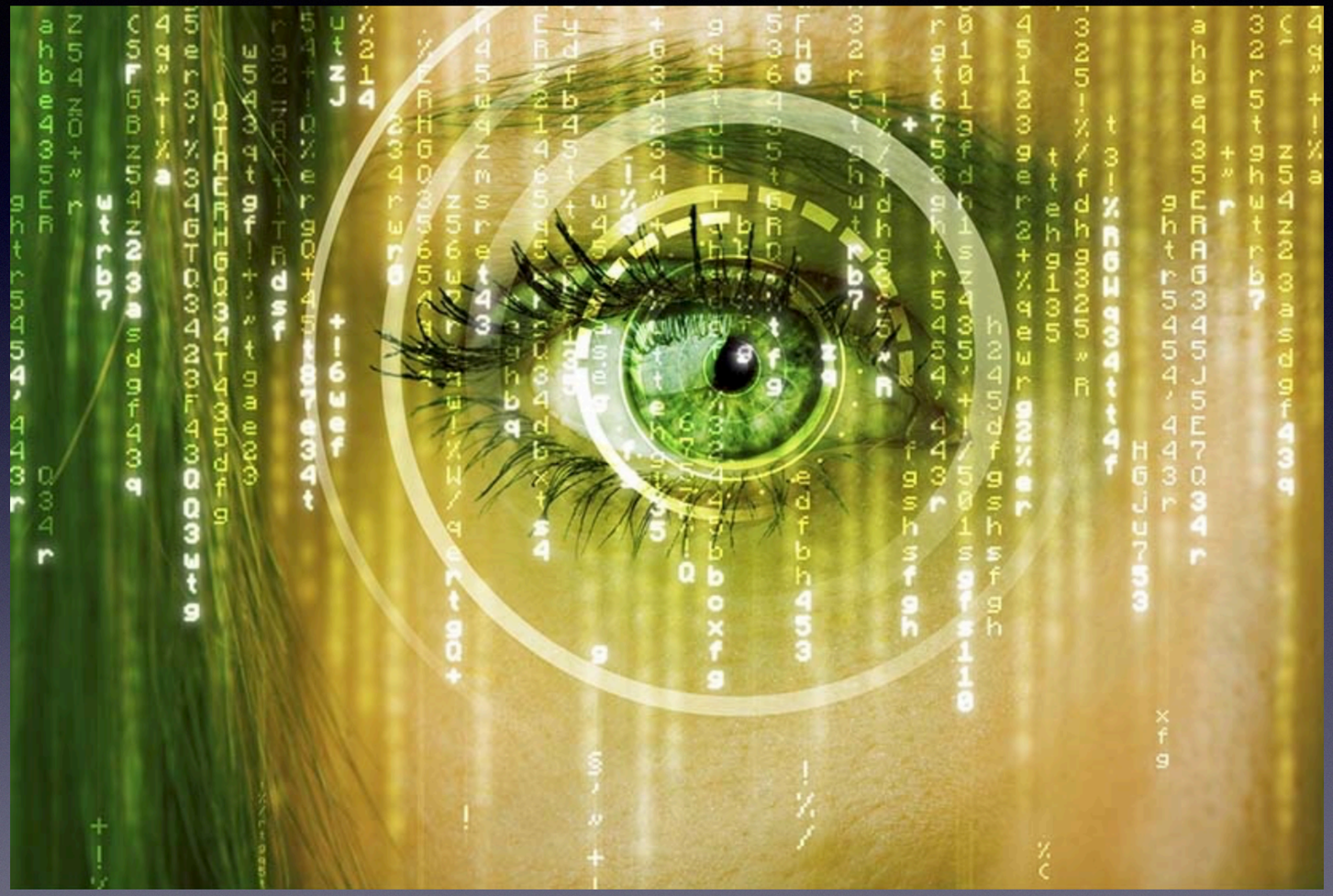
Gitte Furdal Damm



- Aviation since 1995
- Former pilot
- About Human Factors
- MSc program Human Factors and System Safety Lund University

“Risk is in the eye of the beholder”

(Diane Vaughan, 1986, p. 62)



ABOUT HUMAN FACTORS

Risk - present or absent?

“ ..particular concerns have been raised regarding the negative impact on flight safety when crew members are exposed to oil or hydraulic fluid fumes or smoke and experience acute symptoms in flight” (ICAO, Cir 344-AN/202, 2015, p. 1)

“ Contaminated air is not a flight safety issue. The air quality on a passenger jet aircraft is similar or better than what is observed in normal indoor environments” (EASA)

“ In the past, oil leaks and cabin/flight deck odours and fumes may have come to be regarded as a nuisance rather than a potential flight safety issue” (British Aerospace)

“ ..as the aircraft passed through 4000 ft. both flight crew detected a sudden, very strong smell. The commander described it as a ‘manure smell”; “like a field which had just been muck spread”. He described the smell instantly “hitting him” in the back of the throat. There was no smoke or obvious source of the smell. The co-pilot described it as a “ strong sweaty socks” smell. He reported feeling itchy skin around his eyes and a scratchy throat.” (AAIB Bulletin: 9/2020, p. 2)



“Numerous other similar fume events have been reported to the AAIB and the CAA. This report reviews five other similar events which occurred with the same operator on the same aircraft type. It was not possible to identify the cause of these events, but, several common features have been identified” (AAIB Bulletin: 9/2020,p.1)

ABOUT HUMAN FACTORS

The CAA mandatory occurrence reporting (MOR) scheme has received 674 reports of smell, smoke or fumes events in the past 12 months and 3,166 in the last five years. In 2019, the operator involved in this event reported 536 smell, smoke or fumes events to the CAA, of these 398 involved the Airbus A320 series aircraft.

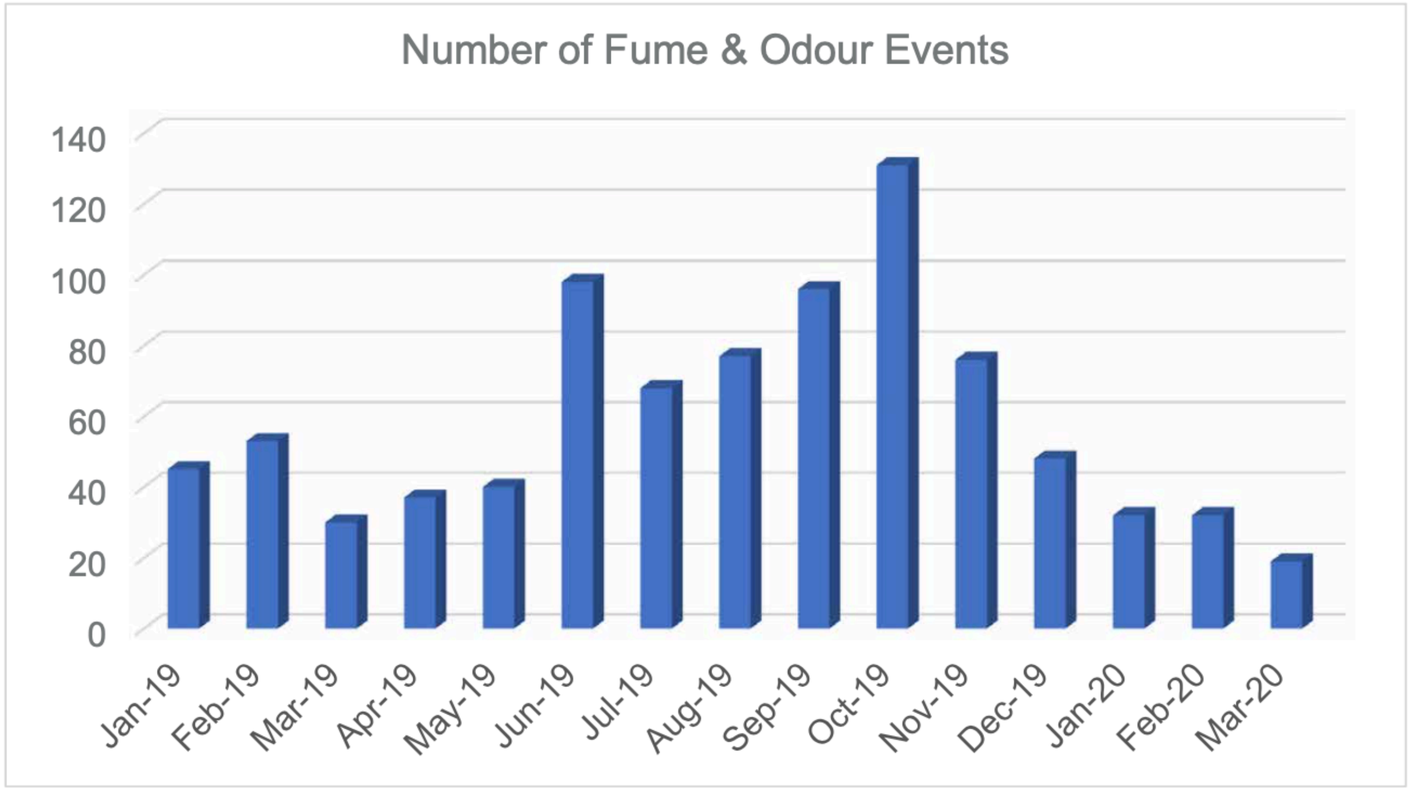


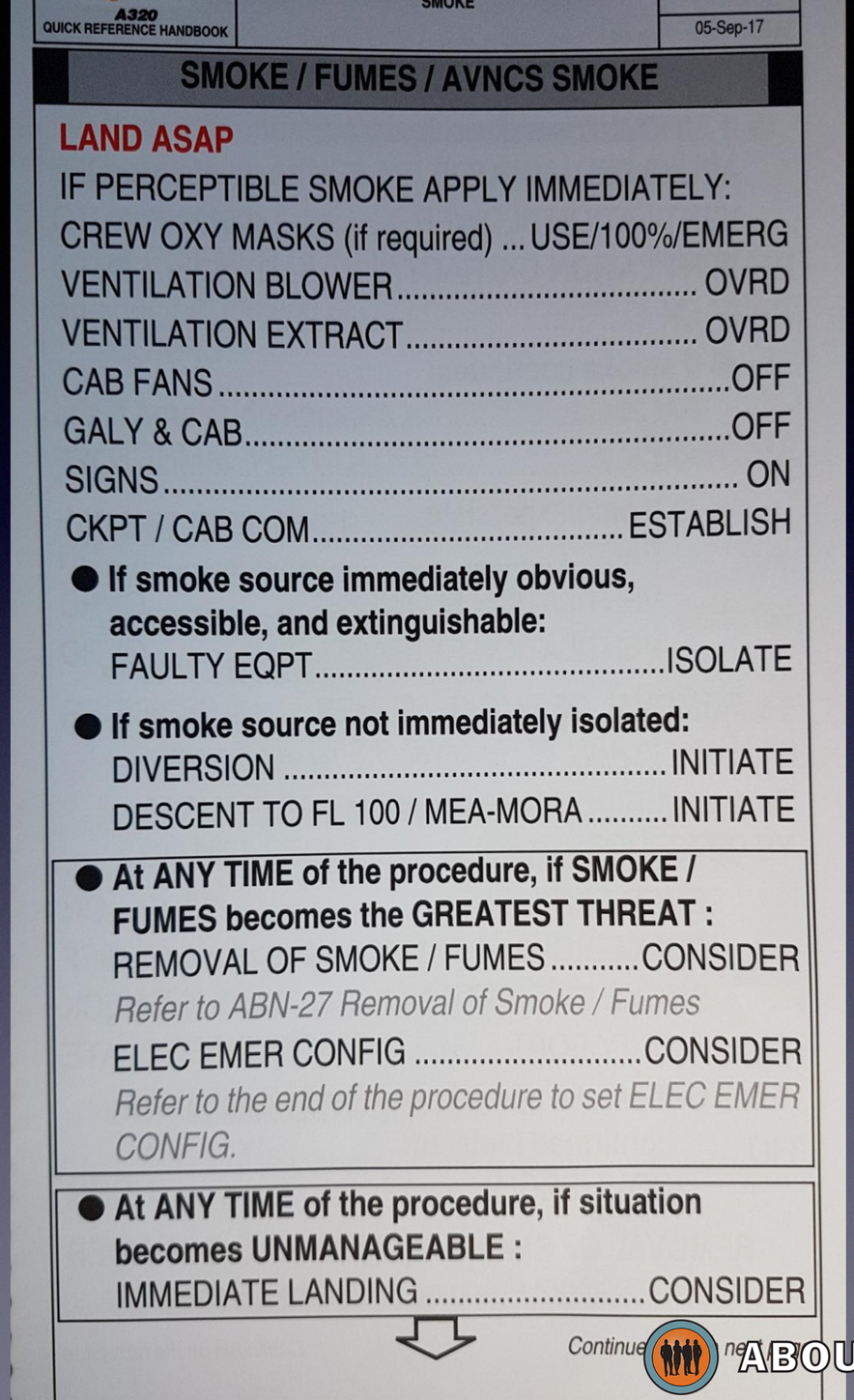
Figure 3

Fume and odour events on the operator's Airbus A320 fleet in 2019 and early 2020

Is there a pattern of risk to address?

- In many cases the pilots described a faint smell during climb out on departure
- When events occurred, the pilots described the fumes and odours reappearing on descent and in a number of cases at about 4000 ft. in stable flight
- The presence of fumes can have a rapid and adverse effect on flight crew
- The fumes described in these events were invisible
- When the fumes were detected by the cabin crew, they appear to linger in the galley areas
- The use of the smoke and fumes abnormal and emergency procedures appeared to alleviate, but not completely eradicate, the effects in the main cabin

(AAIB Bulletin: 9/2020, p. 15).



A320
QUICK REFERENCE HANDBOOK

SMOKE

05-Sep-17

SMOKE / FUMES / AVNCS SMOKE

LAND ASAP

IF PERCEPTIBLE SMOKE APPLY IMMEDIATELY:

CREW OXY MASKS (if required) ... USE/100%/EMERG

VENTILATION BLOWER ..... OVRD

VENTILATION EXTRACT ..... OVRD

CAB FANS ..... OFF

GALY & CAB ..... OFF

SIGNS ..... ON

CKPT / CAB COM ..... ESTABLISH

● **If smoke source immediately obvious, accessible, and extinguishable:**

FAULTY EQPT ..... ISOLATE

● **If smoke source not immediately isolated:**

DIVERSION ..... INITIATE

DESCENT TO FL 100 / MEA-MORA ..... INITIATE

● **At ANY TIME of the procedure, if SMOKE / FUMES becomes the GREATEST THREAT :**

REMOVAL OF SMOKE / FUMES ..... CONSIDER

Refer to ABN-27 Removal of Smoke / Fumes

ELEC EMER CONFIG ..... CONSIDER

Refer to the end of the procedure to set ELEC EMER CONFIG.

● **At ANY TIME of the procedure, if situation becomes UNMANAGEABLE :**

IMMEDIATE LANDING ..... CONSIDER

Continue on next page

“ The use of the SMOKE/ FUMES/ AVNCS SMOKE checklist would not have given the flight crew any effective guidance, because it was geared towards identification and isolation of any possible source of smoke in the airplane. Therefore it is not suited to determine and eliminate the various causes of smells. (BFU 15-0006-PX).

ABOUT HUMAN FACTORS

Humans adapt to make things work



“ Human adaptability is marvellous, and humans always “finish the design” because there are inevitably gaps between the technology and an uncertain, changing world” (Wears & Hettinger, 2013, p. 338).



“ The flight crew’s previous experience suggested that if the smell was going to reoccur it was most likely to occur when thrust was reduced for descent so, during the cruise, they discussed their actions if the smell returned and reviewed the SMOKE/ FUMES/AVNCS SMOKE checklist” (AAIB-26125, p. 2)

Safety or not?



“People are the most adaptable element in any complex work system. This adaptability is essential in making things work, both in ordinary and especially in extraordinary circumstances” (Wears & Hettinger, 2013, p. 338)



“ Due to the potential flight safety implications, it is beneficial to provide guidance and instructional material to enable the crew members to promptly recognize and respond to suspected air supply system-sourced fumes, as well as enable aircraft maintenance technicians (ATM) to identify the source of the contaminants and to *correct the issue*” (ICAO, Cir 344-AN/202, 2015 p. 1).



“ Users should not have to adapt to support systems; rather, systems should be adapted to support users. (Wears & Hettinger, 2013, p.1).



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Editors: Dieter Scholz, Susan Michaelis

Cabin Air Quality Monitoring – Organophosphates Sampling during Fume Events in Australia

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Extended Abstract

Purpose: The Australian Federation of Air Pilots (AFAP) presented the results of organophosphate analysis from cabin air sampling on VH-registered aircraft during pilot-reported fume events. As part of a wider Global Cabin Air Reporting System (GCARS) study, AFAP pilot members undertook a small-scale initial trial of the new GCARS reporting tool. Traces of the neurotoxin Tricresyl Phosphate (TCP) had previously been found in air samples taken on board various aircraft in other studies. The AFAP and its pilot members have an ongoing interest in cabin air quality and better understanding the extent and frequency of the incidence of TCP and other organophosphates in reportable fume events.

Methodology: Cabin air samples were collected by pilots during a reportable fume event using a small personal air monitor device – the 'VN sampler'. This small air sampling system employing standard air filter sampling technology was used to monitor cabin air in domestic passenger aircraft flying domestically within Australia over the trial period from July 2018 to June 2019. The device is a small ABS constructed cylinder (5 cm diameter x 9 cm height) that can be readily operated by pilots who were instructed to open the sampler if they detected a reportable fume event and collect ambient cabin air for up to one hour. Once activated, the sampler was in operation for the duration of the flight or for the life of the batteries (approximately 1 hour), whichever is shortest. The VN samplers were returned to a laboratory where the standard 37 mm filters (onto which volatile compounds had adhered) were removed and any organophosphates present were analysed by gas chromatography-mass spectrometry (GC-MS). The only air sampler to be approved by the Federal Aviation Administration, the VN sampler has previously been shown to be capable of monitoring air concentrations of TCP isomers in aircraft above 4.5 ng/m^3 (van Netten 2009). Note: ng, nanogram, 10^{-9} g.

Findings: A set of 20 samples taken by pilots during Australian domestic flights and analysed by GC-MS, showed the presence of organophosphates in 16 (80%) samples. Samples were taken on reasonable suspicion of a fume event that would be "reportable", usually (but not always) resulting from a notable odour (or smoke in more obvious incidents). Often the notable odour was so mild as to be imperceptible to some crew members. For instance, sample 115 was collected when only one crew member detected a very mild smell. This aircraft had another fume event six weeks

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Related presentation: https://doi.org/10.5281/zenodo.5567722.

later which engineers attributed to oil leaking from the auxiliary power unit (APU) into its air intake. Analysis of this set of samples indicated exposure to Tricresyl Phosphate (TCP) levels ranging from LOD to 3872 ng/m^3 (detection limit < 4.5 ng/m^3). Of the total samples analysed, 80% contained significant/high concentrations of Tricresyl Phosphate (TCP) and other organophosphates including Tributyl Phosphate (TBP). Given levels of TBP and TCP in normal flights are usually close to or below our detection limit, all the collected and analysed samples (except sample 83) identified that these organophosphates were present in significant concentrations.

Research Limitations: This small-scale trial was only a study of a limited number of reportable fume events (n=20). To obtain a better indication of the incidence of organophosphates during fume events, a larger study would be required. Elevated levels of Tributyl Phosphate (TBP) have been associated with the use of the auxiliary power unit (APU) in the aircraft. A larger-scale, controlled experiment designed to adjust for other variables such as this would be required.

Practical Implications: Tricresyl Phosphate (TCP) is an indicator of bleed air contamination of aircraft cabin air. It was noted that analysis of sample 119 gave one of the higher results for TCP (and TBP) yet there was barely a detectable odour during the flight. The implications for further research are significant. This data appears to indicate the value of continuous real-time air quality monitoring in the cabin to reveal any fume events that may escape reporting reliant on rudimentary detection by air crew through a noticeable odour or smoke.

Social Implications: The outcomes of this study have been presented to airline executives and others within the Aviation industry in attendance at the 2021 ACIAC.

Value and Originality: This trial study is the first multi-scale collection of real-time cabin air sampled by pilots *during* (rather than following) reportable fume events (and subsequently analysed to collect TCP isomers and TBP data).

Keywords

cabin air sampling, personal air monitor, organophosphates, air pollutants analysis, indoor air pollution, aircraft standards, air monitoring, gas chromatography, mass spectrometry

List of References

VAN NETTEN, C., 2009. *Design of a Small Personal Air Monitor and its Application in Aircraft*. In: Science of The Total Environment, vol. 407, no. 3, pp. 1206-1210, 15 January 2009. Available from: https://doi.org/10.1016/j.scitotenv.2008.07.067, Archived at: https://perma.cc/HK88-TUVD.

Acknowledgements

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About the Author

Marcus Diamond received the B.Sc. degree from the University of Melbourne, Victoria, Australia (1986) and later a Commercial Pilot Licence and an Air Transport Pilot Licence (1996). He has worked as an airline captain in Australia, New Zealand and Papua New Guinea and is currently the Safety & Technical Manager at the Australian Federation of Air Pilots in Melbourne, Australia. Captain Diamond also serves on the AusALPA safety and technical committee and has attended past Aircraft Cabin Air conferences.

AUSTRALIAN FEDERATION
OF AIR PILOTS

Cpt Marcus Diamond

Cabin Air Quality Monitoring –
Organophosphates Sampling during Fume Events in Australia

International Aircraft Cabin Air Conference 2021
Online, 15-18 March 2021

WHY SAMPLE? //

Dozens of concerned and affected pilots

There are unanswered questions

Unactioned findings from Gov’t reviews & enquiry

Refutable statements in other sampling studies

Adding to the data

Our industry needs to acknowledge the problem and improve

2000 AUSTRALIAN SENATE ENQUIRY //

Recommendation 3

The Committee believes that development of an appropriate and accurate test for the presence of any chemical fumes in aircraft cabins is essential. The Committee accordingly recommends that CASA liaise with operators to develop a standardised, compulsory monitoring program which provides for testing cabin aircraft air during fume events.

Recommendation 8

The Committee recommends that CASA assess how quickly fitting appropriate high-grade air filters can be made mandatory for all commercial airliners flying in Australia to minimise any deleterious health effects arising from poor aircraft cabin air on crew and passengers. In view of proposed standards currently under consideration in the United States of America and elsewhere, such a system should ideally be designed to remove at least 99% of particles 0.3 micron or larger from recirculated cabin air.

The committee received considerable evidence criticizing aspects of the regulatory regime for the aircraft and focusing on issues that should be taken up by regulators, such as:

- Oil leaks & exposure to oil fumes
- Responses to crew complaints
- Testing procedures for cabin air
- Modification measures necessary to remedy fume contamination

RECOMMENDATIONS //

Domestic and international laws and standards for the quality of air in aircraft

2.21 Australia has adopted design standards and requirements for all aircraft which are certified to operate in Australian airspace. As noted above, these include United States Federal Aviation Regulations (FAR's) (section 25) and joint European Aviation Regulations (section 25). Both standards have requirements dealing with cabin ventilation and contamination in an aircraft. FAR 25.831 requires:

> (a) Under normal operating conditions and in the event of any probable failure conditions of any system which would adversely affect the ventilating air, the ventilation system must be designed to provide a sufficient amount of uncontaminated air to enable the crewmembers to perform their duties without undue discomfort or fatigue and to provide reasonable passenger comfort….

CASA confirmed to the Committee:

Perhaps an important section is a statement under section 25.831 of FAR 25, which says that: 'Crew and passenger compartment air must be free from harmful or hazardous concentrations of gasses and vapours.' That is the only statement that is in there at present. What constitutes 'harmful' or 'hazardous' is left up to other standards, and generally they are getting into the health standards.[22]

(b) Crew and passenger compartment air must be free from harmful or hazardous concentrations of gases or vapours …

(c) There must be provisions made to ensure that the conditions described in para B … are met after reasonably probable failure or malfunctioning of the ventilating, heating, pressurization or other systems and equipment.

CASA'S VIEW //

CASA outlined in a submission its views on air quality on the Bae 146 aircraft. According to the authority:

> A team of Australian medical experts reviewed the test methods and results and has declared that there is no contaminant present in the cabin environment that will induce any long term or permanent effects on the passengers or crews.
>
> In particular, **at no time was tricresylphosphate (TCP) ever identified in any sample gathered in an Australian aircraft.**

Action Recommended:

It is believed the quality of the air to meet certification standards for this type of aircraft should be tested by Gas Liquid Chromatography to determine levels of organophosphates and their interaction with hydrocarbons/volatile organic compounds in the ambient cabin air.

EPAAQ FORMED 2007 //

EPAAQ was unable to reach definitive conclusions saying it is an area of research where "reasonable people's views can differ".

CASA considered it wouldn't propose any major policy or regulatory decisions based on that evidence. It also noted many of the EPAAQ's recommendations fell outside the ambit of CASA's functions set out in the *Civil Aviation Act* 1988 (Cth)

Civil Aviation Advisory Publication (CAAP) advises:

(c) smoke, toxic or noxious fumes inside the aircraft is considered a major defect

FAA response to 2002 CAQPCCA report acknowledges:

"FAA rulemaking has not kept pace with public expectation and concern about air quality and does not afford explicit protection from particulate matter and other chemical and biological hazards. No present airplane design fulfills the intent of 25.831 because no airplane design incorporates an air contaminant monitoring system to ensure the air provided is free of hazardous contaminants."
(Federal Aviation Administration, 2005)

REGULATOR RESPONSES //

EPAAQ report, CASA said:

Contamination of aircraft cabin air by bleed air – a review of the evidence (up to September 2009)

The panel's inability to reach definitive conclusions highlights the fact that this is an area of research where reasonable people's views can differ. In the circumstances, **it would not be prudent for CASA to make major policy and regulatory decisions on the basis of inconclusive evidence.**

EASA found:

- a causal relationship between the reported health symptoms and oil/hydraulic fluid contamination has not been established. **As there is no conclusive scientific evidence available, the Agency is not able to justify a rulemaking task to change the existing design or certification specifications.**

OTHER REPORTS //

Cranfield University: Are there organophoshates in cabin air?

- In over 95% of the cabin air samples, **no detectable amounts or ToCP or TCP** were found. **TBP was detected more routinely, but not in the majority of samples**.

EASA study 2017: Final Report Preliminary Cabin Air Quality Measurement Campaign

- Study results indicate that under routine aircraft operations, **contaminant level in aircraft cabins are mostly similar to those in residential and office buildings**
- In more than 95% of all cabin air samples, **no detectable amounts or ToCP or other TCP's were found.**
- In conclusion: "... A continuation of the previous measurement series is also not considered as constructive, since **encountering a real** TCAC-**event**, which needs to be investigated in order to answer some of the questions, **remains very unlikely** …"

Is this a "pretended" problem?
Do we know the isomers to look for?

SENATE'S FINDINGS - ATTITUDE OF AIRLINES TO STAFF'S REACTIONS TO FUMES //

The response to employees showing symptoms of toxicity showed a **lack of understanding of duty of care.**

Information issued to staff on the issue has attempted to **minimize the problem using language of public relations.**

The basic approach to injured staff appears to be **adversarial.**

Staff have been **bullied and have been victimized**.

Workers have been **forced to keep working** in conditions that continue to **aggravate their health, in some cases to permanent incapacity.**

Staff have been **offered demeaning duties**, and genuine attempts at rehabilitation have been lacking.

ATSB – 323 REPORTED EVENTS IN 2018//

Australian Government
Australian Transport Safety Bureau

Date range: From 16 Jan 2018 to 15 Jan 2019
Location: All
Occurrence Category: All
Occurrence Type: Fumes
Aircraft and Airspace: All

Date	ATSB Reference Number	Category	ATSB Investigation	Location	Latitude	Longitude	State	Aircraft Manufacturer	Model	Operation Type	Operation Sub Type	Airspace Type	Airspace Class	Summary
12/02/2018	201800507	Incident		Perth Aerodrome	31° 56.418' S	115° 58.02' E	WA	Airbus	A320	Air Transport High Capacity	Passenger	CTR	C	During pre-flight preparations, fumes were detected in the cockpit and cabin.
12/04/2018	201801808	Incident		abeam Mooliabeenie (ALA)	31° 19.998' S	116° 1.002' E	WA	The Boeing Company	737	Air Transport High Capacity	Passenger	CTA	A	During cruise, the cabin crew observed smoke emanating from an in-flight entertainment screen. Engineers replaced the in-flight entertainment screen.
12/06/2018	201802812	Incident		near Perth Aerodrome	31° 56.418' S	115° 58.02' E	WA	Fokker Aircraft B.V.	F28	Air Transport High Capacity	Passenger	CTA	A	During climb, cabin crew detected fumes emanating from an oven.
12/09/2018	201805646	Incident		abeam Geraldton Aerodrome	28° 47.772' S	114° 42.45' E	WA	Fokker Aircraft B.V.	F28	Air Transport High Capacity	Passenger	CTA	A	During climb, fumes were detected in the cabin. The engineering inspection did not determine the source of the fumes.
12/10/2018	201807271	Incident		Perth Aerodrome	31° 56.418' S	115° 58.02' E	WA	Embraer-Empresa Brasileira De	EMB-120	Air Transport Low Capacity	Passenger	CTR	C	During pre-flight procedures, fumes were detected in the cockpit and cabin. The engineering inspection revealed the left hand pressure regulating shutoff valve was
12/10/2018	201807267	Incident		near Perth Aerodrome	31° 56.418' S	115° 58.02' E	WA	Fokker Aircraft B.V.	F28	Air Transport High Capacity	Passenger	CTR	C	During descent, fumes were detected in the cabin. The engineering inspection did not determine the source of the fumes.
12/10/2018	201807304	Incident		near Perth Aerodrome	31° 56.418' S	115° 58.02' E	WA	Fokker Aircraft B.V.	F28	Air Transport High Capacity	Passenger	CTA	C	During descent, fumes were detected in the forward galley. The engineering inspection did not determine the source of the fumes.
12/12/2018	201808958	Incident		near West Angelas Aerodrome	23° 8.1' S	118° 42.402' E	WA	Fokker Aircraft B.V.	F28	Air Transport High Capacity	Passenger	CTA	A	During cruise and again in the next sector, fumes were detected in the cabin. The engineering inspection revealed the left and right hand water separator drains were
13/02/2018	201800486	Incident		near Broome Aerodrome	17° 56.982' S	122° 13.668' E	WA	Fokker Aircraft B.V.	F28	Air Transport High Capacity	Passenger	CTA	A	During descent, fumes were detected in the cockpit and cabin. The engineering inspection could not determine the source of the fumes.
13/03/2018	201801168	Incident		Gold Coast Aerodrome	28° 9.87' S	153° 30.282' E	QLD	The Boeing Company	737	Air Transport High Capacity	Passenger	CTR	C	During engine shut-down, fumes were detected in the cockpit and cabin. The engieering inspection did not reveal the source of the fumes.
13/06/2018	201802840	Incident		Perth Aerodrome	31° 56.418' S	115° 58.02' E	WA	S.A.A.B. Aircraft Co	340	Air Transport Low Capacity	Passenger	CTR	C	During preparation for flight, fumes were detected in the cockpit emanating from the avionics.
13/06/2018	201802835	Incident		near Perth Aerodrome	31° 56.418' S	115° 58.02' E	WA	Fokker Aircraft B.V.	F28	Air Transport High Capacity	Passenger	CTA	C	During descent, fumes were detected in the cockpit and cabin.
13/07/2018	201803619	Incident		near Perth Aerodrome	31° 56.418' S	115° 58.02' E	WA	Fokker Aircraft B.V.	F28	Air Transport High Capacity	Passenger	CTR	C	During approach, fumes were detected in the cabin. The engineering inspection did not reveal the source of the fumes.
13/08/2018	201804823	Incident		Perth Aerodrome	31° 56.418' S	115° 58.02' E	WA	The Boeing Company	717	Air Transport High Capacity	Passenger	CTR	C	During push back, fumes were detected in the cabin. The source of the fumes was traced to APU exhaust air being taken in by an engine on start up and spreading
13/08/2018	201804647	Incident		near Perth Aerodrome	31° 56.418' S	115° 58.02' E	WA	Fokker Aircraft B.V.	F28	Air Transport High Capacity	Passenger	CTA	C	During descent, fumes were detected in the cabin. Engineers replaced the coalescer bags.
13/10/2018	201807344	Incident		near Darwin Aerodrome	12° 24.882' S	130° 52.602' E	NT	Airbus	A320	Air Transport High Capacity	Passenger	CTA	A	During descent, fumes were detected in the cockpit.
13/10/2018	201807307	Incident		near Broome Aerodrome	17° 56.982' S	122° 13.668' E	WA	Fokker Aircraft B.V.	F28	Air Transport High Capacity	Passenger	CTR	D	During approach, fumes were detected in the cabin. The engineering inspection did not reveal the source of the fumes.
13/11/2018	201808138	Incident		Avalon Aerodrome	38° 2.37' S	144° 28.17' E	VIC	Airbus	A320	Air Transport High Capacity	Passenger	CTR	D	During cruise, fumes were detected in the cabin. The engineering inspection did not determine the source of the fumes.
13/11/2018	201808135	Incident		Nifty Aerodrome, 195Â° M 111Km	22° 38.022' S	121° 16.83' E	WA	Fokker Aircraft B.V.	F28	Air Transport High Capacity	Passenger	CTA	A	During cruise, fumes were detected in the cabin. Engineering replaced the right air-conditioner coalescer bag.
13/12/2018	201808961	Incident		near Gold Coast Aerodrome	28° 9.87' S	153° 30.282' E	QLD	Airbus	A320	Air Transport High Capacity	Passenger	CTA	C	During cruise, fumes were detected in the cabin. The engineering inspection revealed a leak in the APU.
14/02/2018	201800510	Incident		Coondewanna Aerodrome, 225Â° M 74Km	23° 25.68' S	118° 17.352' E	WA	Airbus	A320	Air Transport High Capacity	Passenger	CTA	A	During descent, fumes were detected in the cockpit and cabin. Engineers replaced the oil pump.

WHY SAMPLE FOR TCP? //

Because the engine oil manufacturers appear to report the TCP content of their products unevenly, **Professor Chris van Netten of the University of British Columbia** analysed the actual TCP content – both total TCPs and the relative amounts of four TCP isomers – in samples of eight aviation engine oils and three aviation hydraulic fluids.

The total TCP content of the eight oils ranged from 2.2 to 5.2% (by weight), and the total TCP content of each hydraulic fluid was zero.

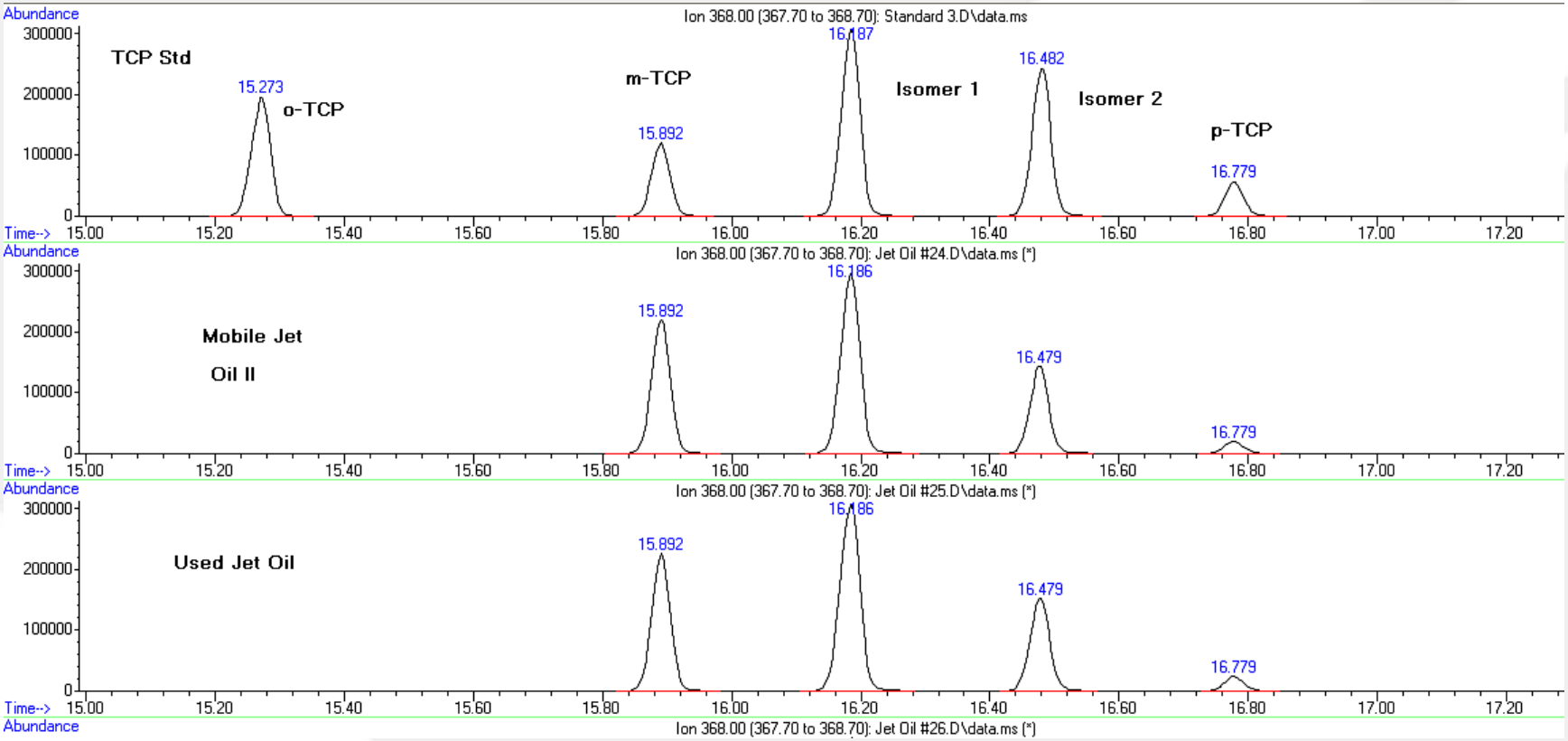
Tricresyl Phosphate (TCP) is an indicator of bleed air contamination of aircraft air

- Highly specific to most jet turbine oils

To assess risk, need to measure the level of exposure to bleed air components

- TCP and its isomers are known neurotoxins
- Important indicator of the presence of all other pyrolysis products

TCP ISOMER PATTERNS FROM JET TURBINE OILS //



Protocols for the use of the VN Sampler for fume events in engine bleed pressurised aircraft cabins.

Rules for activating the VN sampler

- Prepare the sampler when there is a persistent presence of abnormal air quality[1] and the PIC is planning to submit a company pilot report or maintenance entry [2]
- Remove the sampler from the plastic bag and "twist ON" to activate. The sampler may be placed in any convenient position on the flight deck; it does not need to be next an air vent
- Once activated, run the sampler for as long as the flight lasts or until the batteries run out (approximately 1 hour), whichever occurs first. Continue to run the sampler even if the abnormality has disappeared. **Make sure you annotate the time on/off.**
- Keep track of the exposure time and any of the details. i.e. aircraft, date, location and duration of sampling, phase of flight, describe the type of abnormality etc. See attached fume event form
- Close the sampler (twist OFF) and place inside a self-sealing plastic bag that was provided.

The AFAP has provided a stamped return address package for you to post the sampler and this report to the Safety and Technical department

[1] for the purposes of this trial, abnormal air quality or contamination includes the presence of odours, fumes, haze and smoke that may be associated with engine or APU bleed air

[2] remember that under the Australian Transport Safety Investigation Act 2003 section 18 smoke and fumes are an immediately reportable matter. An event must be reported to a nominated official as soon as is reasonably practicable, and a written report submitted within 72 hours

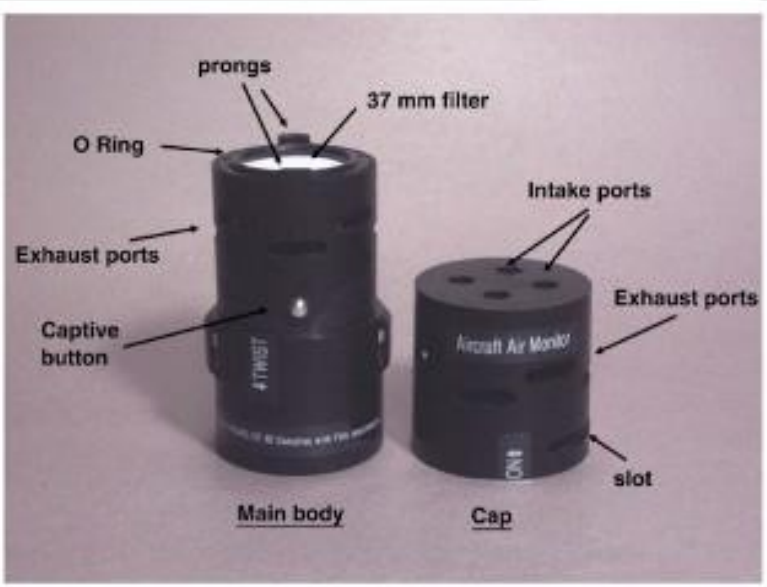


Fig. 2 – VN sampler with cap removed showing details and filter housing.

Please fill in this report if you have activated the VN Sampler device within an aircraft cabin/flight deck.

Name or Sampler #		**Approx' monthly crew hours flown**		**Approx' monthly aircraft cycles flown**	
107B		**60**		**37**	
Date LCL	**2018**	**A/C type**	**NB Jet**	Route or FLT No	X[redacted]
Time of activation LCL	**50 min**	**A/C Reg**	VH - [redacted]		
Company report reference, e.g Maint log, safety report	[redacted]	Phase of flight e.g GND, Eng start, taxi, climb, cze, dsc, app/ldg	**Cruise & descent**	Bleeds On or Off	**On**
				APU, On or Off	**Off**
Odour comments Oil, skydrol, fuel, dirty socks, gym bag, electrical etc	**Oil/dry heated dust**	Fume comments e.g visible, haze, not visible etc	**Not visible**	Contamination comments Likely bleed air? IFE/equipment ? Ovens? etc	**Likely bleed air or ECS oil contamination**
Short report:	**This A/C has exhibited oily odours late on descent recently, including on both sectors today. Not noticed by crew other than the Captain. These mild odours are generally treated as normal. This A/C has had recent fume events involving oil found leaking from the APU. Air sample taken based on reasonable suspicion of the presence of oil in the air conditioning. Request confirmation of oil presence in this sample. Post flight, Capt' had an aggravated chest & dry cough which persisted through the night. Sampling commenced in cruise…….**				

CABIN AIR SAMPLING RESULTS //

October 2018 Australian samples

nanograms (ng) per filter analyzed

sample#	TBP	m-TCP	mmp-TCP	mpp-TCP	p-TCP	Total TCP	Flow rate Liters/ min	Sampling time minutes	Volume Liters of air	TCP/m3 ng	TBP/m3 ng
83 SIM	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1	54	54	LOD	
107 SIM	9.20	<LOD	<LOD	<LOD	<LOD	<LOD	1.2	20.00	24	LOD	383.3
114 SIM	68.00	<LOD	<LOD	<LOD	1.19	1.19	1	35	35.00	34.00	1085.7
115 SIM	31.00	<LOD	2.59	2.06	1.23	5.88	1.00	55.00	55.00	106.90	563.60
119 SIM	89.00	69.95	126.05	80.12	34.73	247.85	1.00	64.00	64.00	3872.60	1390.60
125 SIM	74.00	14.55	26.38	15.46	6.41	62.80	1.10	45.00	49.00	1281.60	1510.20
161 SIM	5.00	4.86	9.78	6.21	2.93	23.78	1.20	40.00	48.00	495.40	104.10
Blank 1	<LOD	<LOD	<LOD	<LOD	<LOD						
Blank 2	<LOD	<LOD	<LOD	<LOD	<LOD						
Blank 3	<LOD	<LOD	<LOD	<LOD	<LOD						
Blank 4	<LOD	<LOD	<LOD	<LOD	<LOD						
LOD	2.08	0.92	2.36	1.83	0.43						

LOD: Limit of detection
SIM: Single Ion Monitoring for Tributyl Phosphate (TBP) and Tricresyl Phosphate (TCP)

Sample #119.
The exposure was calculated on the basis of 64 minutes. It appears however, from the pilot's notes, that the bulk of the TCP and TBP might have been collected during the last segment of sampling. If this was indeed the case, and using the 35-minute sampling period, the exposure could have been as high as **7081.4 nanogram of TCP/m3** and **2542.9 nanograms of TBP/m3.**

Van Netten: Given levels of TBP & TCP in normal flights are usually close to or below our detection limit, **almost all samples, except #83, identify a problem.**

STUDIES MEASURING TCP //

Showing maximum total TCP levels detected						
Study	**Year**	**Country / Region**	**Max. level TCP µg / m3**	**Number of samples**	**number of aircraft**	**number of events**
Denola	2011	Australia	51.3	78	46 individual a/c	9 incidents smoke odour
Fox (PhD)	2012	US	100	?	Single engine study	
Cranfield	2011	UK	37.7	100	5 a/c types	'minor' fumes in 25 flights
Hanhela	2005	Australia	49	80	3 a/c types	no correlation, but some samples taken with canopy open
Fox / Malmo	1999	Sweden	20.3	1	1	(1) engine test
AFAP	2018/19	Australia	**3.872**	**19**	7 a/c, 1 type	**19**

300 different substances – cabin and bleed air studies
Pyrolysed oil 127 + (EASA 2017)

Van Netten: TCP makes up only 3% of jet turbine oil - the reported values should be multiplied by 33 to obtain exposure to all engine oil components

PILOT EXPANDED REPORTS //

October 2018 Australian samples

nanograms (ng) per filter analyzed

sample#	TBP	m-TCP	mmp-TCP	mpp-TCP	p-TCP	Total TCP	Flow rate Liters/ min	Sampling time minutes	Volume Liters of air	TCP/m3 ng	TBP/m3 ng
115 SIM	31.00	<LOD	2.59	2.06	1.23	5.88	1.00	55.00	55.00	106.90	563.60
119 SIM	89.00	69.95	126.05	80.12	34.73	247.85	1.00	64.00	64.00	3872.60	1390.60

Sample 119 - This sample shows one of the higher results for TBP and TCP yet there was barely a detectable odour during the sampled flight. None of the cabin crew detected an odour at all and the pilots detected it only mildly.

This aircraft had a leaking hydraulic pressure line, with extensive hydraulic oil evident on the belly of the aircraft, as shown in the images. Note that the aircraft had been cleaned only 2 weeks earlier. Post incident this aircraft was designated for a further wash "at company convenience". On further investigation, engine oil was found to be present in the APU compartment drain and fumes were noted by the engineers when the APU inlet door was opened.

5 days later a **significant oil fumes event occurred which involved an air return**. No cause was found and **it was suggested that the odour may have been due to "smelly passengers"**. One crew member showed a slightly elevated carboxy haemoglobin level (carbon monoxide) when tested several hours after the event.

This aircraft had also been reported for a strong oily odour on 2 previous recent occasions. After one of the events, engineers assessed the odour to be due to atmospheric ozone in accordance with the Trouble Shooting Manual.

Sample 115 - This sample was taken on reasonable suspicion of a problem due to recent occasional sporadic oily smells. Only one crew member detected a very mild "dusty" or "dry musty" smell during the sampling period. No other crew members detected any odour. This aircraft subsequently had a fumes event 6 weeks later with the crew describing a mild "heated dust-like" odour and then a moderate "sweaty socks" odour. Upon investigation engineers discovered oil leaking from the APU into the APU air intake.

nanograms (ng) per filter analyzed											
sample#	TBP	m-TCP	mmp-TCP	mpp-TCP	p-TCP	Total TCP	Flow rate Liters/ min	Sampling time minutes	Volume Liters of air	TCP/m3 ng	TBP/m3 ng
114 SIM	68.00	<LOD	<LOD	<LOD	1.19	1.19	1	35	35.00	34.00	1085.7

Contaminated cabin air sampling report (VN Sampler):

Please fill in this report if you have activated the VN Sampler device within an aircraft cabin/flight deck.

Name or Sampler #		Approx' monthly crew hours flown		Approx' monthly aircraft cycles flown	
114		65		35	
Date LCL	Oct 2018	**A/C type**	NB Jet	Route or FLT No	[redacted]
Time of activation LCL	34 min	**A/C Reg**	VH - [redacted]		[redacted]
Company report reference, e.g Maint log, safety report	[redacted]	Phase of flight e.g GND, Eng start, taxi, climb, cze, dsc, app/ldg	Cruise & descent	Bleeds On or Off	On
				APU, On or Off	Off
Odour comments Oil, skydrol, fuel, dirty socks, gym bag, electrical etc	Bleach/chllrin e like cleaning fluid	Fume comments e.g visible, haze, not visible etc	Not visible	Contamination comments Likely bleed air? IFE/equipment ? Ovens? etc	Possible cleaning agent, possible oil
Short report:	Cabin crew reported bleach or chlorine like odour in forward cabin.From row 5 forward. Not detected in the flight deck.....Odour detected in cruise and present until after landing. One cabin crew also detected a "sweaty socks smell" this cabin crew felt nauseous soon after t/off. Another cabin cew had a headache. Neither pilot could smell anything unusual. The VN sampler was startd approx 10 min's before descent until arrival at the gate. The sampler was run for 34 min's. The cause was later attributed by engineering to mixing of twosoaps in the forward lavatory. However Captain suspects contaminated air.....				

Van Netten: Sample #114 Significant TBP was detected as well as a trace of TCP.
Again, as above, a high acute exposure could have been present during the sampling time.

APU HYDRAULIC OIL INGESTION //

nanograms (ng) per filter analyzed

sample#	TBP	m-TCP	mmp-TCP	mpp-TCP	p-TCP	Total TCP	Flow rate Liters/ min	Sampling time minutes	Volume Liters of air	TCP/m3 ng	TBP/m3 ng
83 SIM	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	1	54	54	LOD	
107 SIM	9.20	<LOD	<LOD	<LOD	<LOD	<LOD	1.2	20.00	24	LOD	383.3
114 SIM	68.00	<LOD	<LOD	<LOD	1.19	1.19	1	35	35.00	34.00	1085.7
115 SIM	31.00	<LOD	2.59	2.06	1.23	5.88	1.00	55.00	55.00	106.90	563.60
119 SIM	89.00	69.95	126.05	80.12	34.73	247.85	1.00	64.00	64.00	3872.60	1390.60
125 SIM	74.00	14.55	26.38	15.46	6.41	62.80	1.10	45.00	49.00	1281.60	1510.20
161 SIM	5.00	4.86	9.78	6.21	2.93	23.78	1.20	40.00	48.00	495.40	104.10



APU hydraulic oil ingestion aligns with detected TBP

RAW DATA SECOND SAMPLE SET //

ng/filter					
	TBP	m-TCP	mmp-TCP	mpp-TCP	p-TCP
Sample 102 SIM	57.15	5.76	12.88	7.31	2.63
Sample 68 SIM	96.30	<LOD	<LOD	<LOD	<LOD
Sample 69 SIM	68.08	<LOD	<LOD	<LOD	<LOD
Sample 71 SIM	68.87	0.96	2.00	1.19	<LOD
Sample 81 SIM	83.17	<LOD	<LOD	<LOD	<LOD
Sample 163 SIM	112.84	1.87	7.09	7.62	3.87
Sample 112-1 SIM	165.19	<LOD	<LOD	<LOD	<LOD
1-Con(Process control) SIM	51.32	<LOD	<LOD	<LOD	<LOD
Blank 1	<LOD	<LOD	<LOD	<LOD	<LOD
Blank 2	<LOD	<LOD	<LOD	<LOD	<LOD
Blank 3	<LOD	<LOD	<LOD	<LOD	<LOD
Blank 4	<LOD	<LOD	<LOD	<LOD	<LOD
LOD:	2.08	0.92	2.36	1.83	0.43

LOSS OF MEDICAL – REPORT EXTRACTS //

MEDICAL PANEL

CONSTITUTED PURSUANT TO THE WORKPLACE INJURY REHABILITATION AND COMPENSATION ACT 2013

/9/17	"Shutdown fumes"
/2/18	"Strong oil fumes in cruise"
/2/18	"Dry dusty fumes in flight deck only"
/3/18	"Fumes PAN SYD MEL"

/4/18	"Hydraulic Leak. Severe Hyd residue"
/4/18	"Hydraulic Leak"
/6/18	"Fumes descent"
/6/18	"Fumes again Cabin crew report post flight"
7/18	"Hydraulic leak/Staining Fume Risk"
/7/18	"Cumulative Respiratory effects"
/2/19	"Smell on start"
/3/19	"Transient smell on start (oily)"

Hair sampling confirming a presence of chemicals including tri-cresyl phosphate (TOCP) in his system,

I found offered history most compelling and could not exclude the possibility of a syndrome secondary to chronic airborne chemical exposure.

report by Dr proposed a link between exposures derived from his employment and his subsequent symptoms, and concluded with the recommendation that should not fly again in an aircraft in which fume events were possible,

Report: Opinion: Treating doctor correspondence, Serial consultations Enduring and fluctuating symptoms of cough and wheeze, but additional non-specific, systemic symptoms such as malaise and headache. …there was evidence of tri-cresyl phosphate exposure and organophosphate exposure in specialist pathology sampling..

Although not a generally accepted term,…case is consistent the diagnosis of "aerotoxic syndrome".

There are ample grounds to surmise that symptoms are consistent with airborne chemical fumes used in the aviation.

There is evidence that in some cases, symptoms can endure indefinitely.

Treatment is supportive.

Captain Marcus Diamond

BSc *Melb*, ATPL *Aus, NZ, PNG*

Safety & Technical Manager

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ULB

Study on Aircraft Bleed Air Contamination by Engine Oil

Experimental and Numerical Investigation of Dispersed Air-Oil Two-Phase Flow through the Environmental Control System

M. Di Matteo, O. Berten, and P. Hendrick

Speaker: Mariano Di Matteo
Mariano.Di.Matteo@ulb.be

AERO/ THERMO/ MECHANICS

Aircraft Cabin Air
International Conference 2021
15-18 March 2021

Outline

Introduction

Methodology

Test results

Conclusions

Introduction

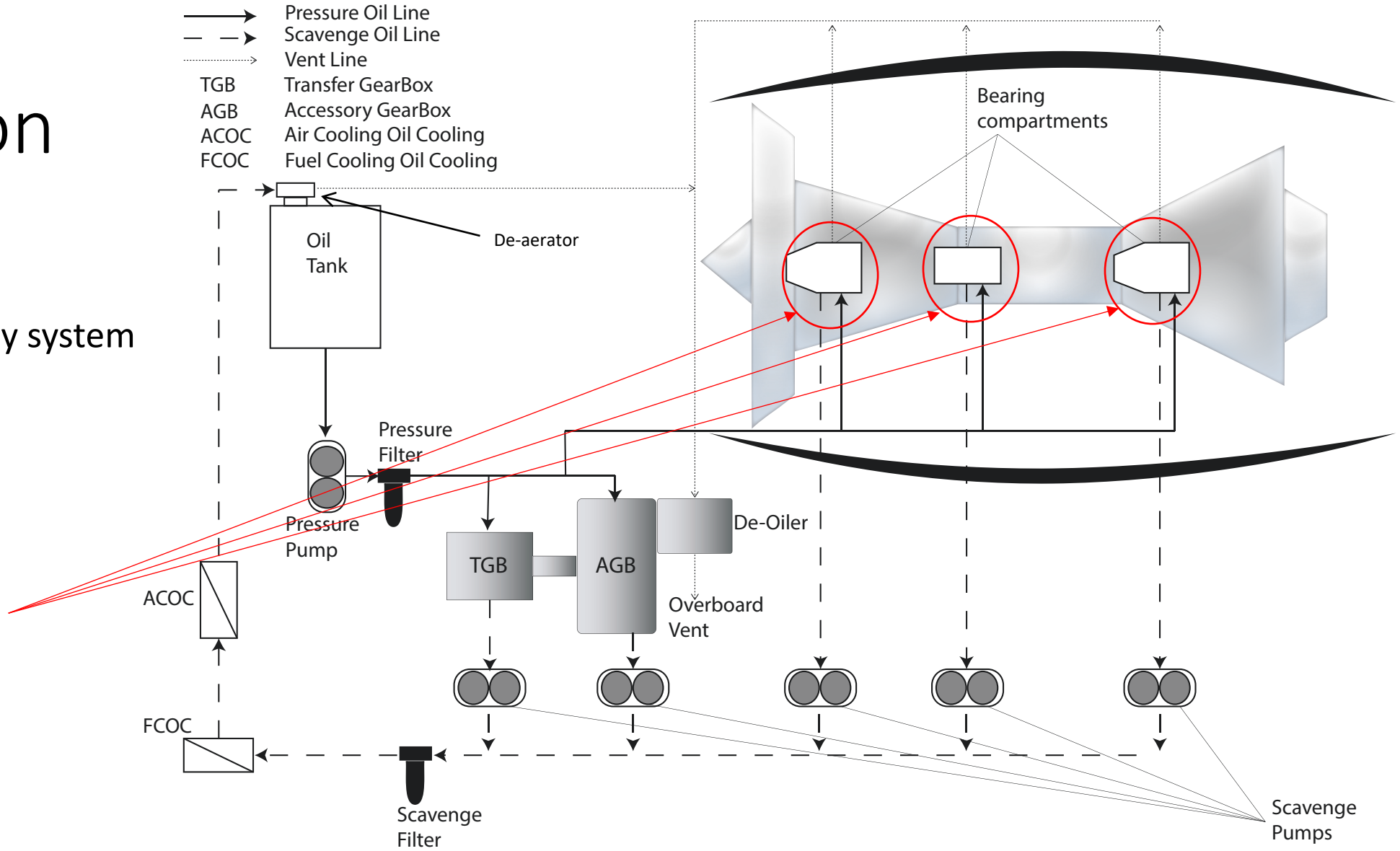
- Environmental Control System supplies the cabin with fresh air at a certain pressure and temperature
- The air used by ECS is obtained by filtering and cooling the aero-engine compressor bleed air
- Bleed air is extracted from the compressor of the aero-engines or the APU
- A concern is the contamination of the bleed air by aero-engine oil

Introduction

Three oil subsystems:

- Storage and supply system
- Scavenge system
- Venting System

Failure at the level of the bearing chamber seals can lead to contamination

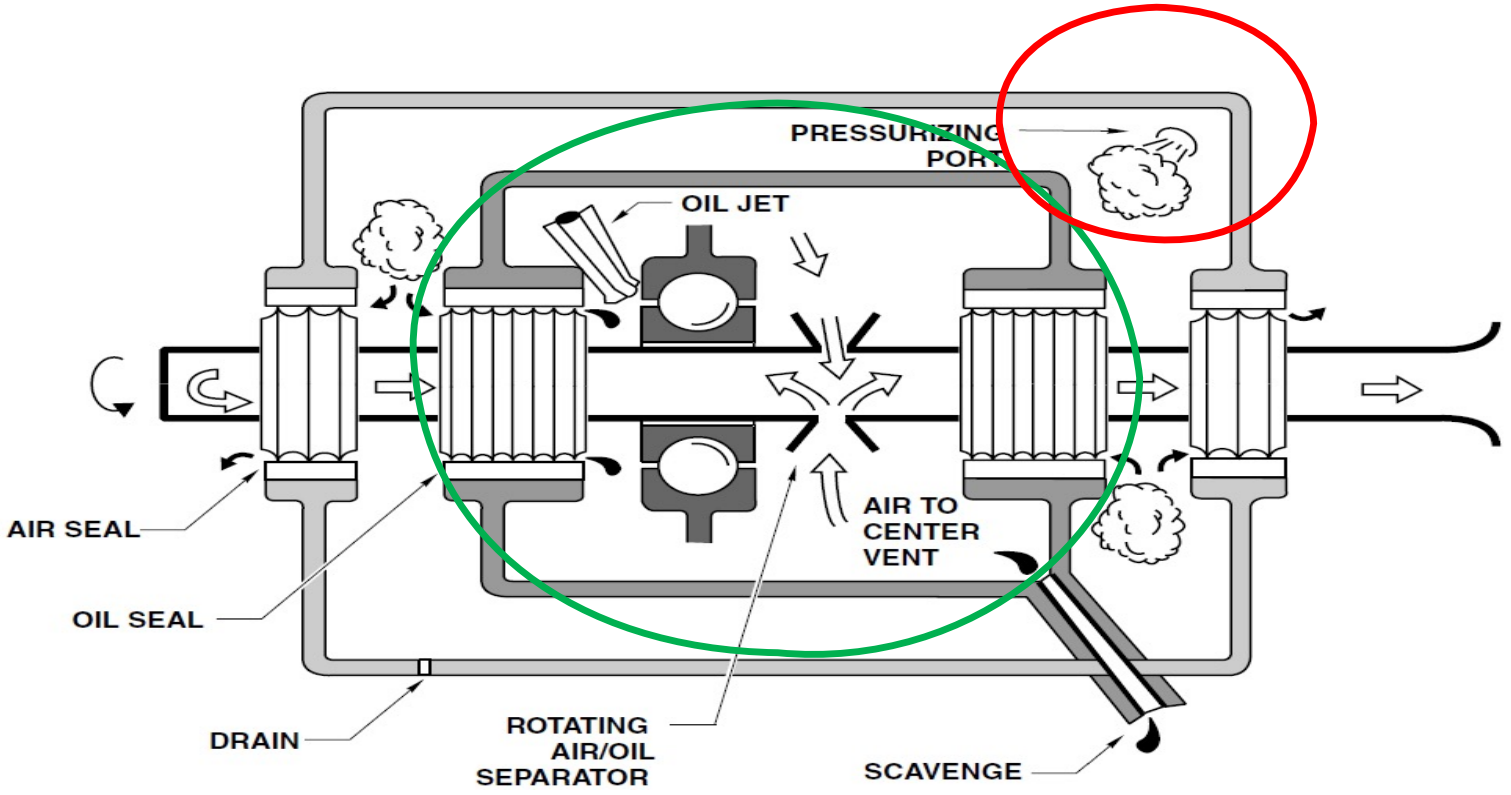


Introduction

Origin of the two-phase flow of oil and air

Aim of this study is to investigate the air-oil two-phase flow through the full piping system

Pressurizing port can become the problem during transients …



Introduction

There are three different exits for the air-oil two-phase flow:

Engine level:

- Pressurization pipe
- Vent line

Aircraft level:

- Environmental Control System

Methodology

Experimental phase:

- Droplet size measurement at inlet and outlet of piping system using the laser diffraction technique

Particle Measurement:

- Laser Helos-Vario/KR
- Measure droplet size from 0,5/0,9 to 175 µm (diameter)



Methodology

Experimental phase

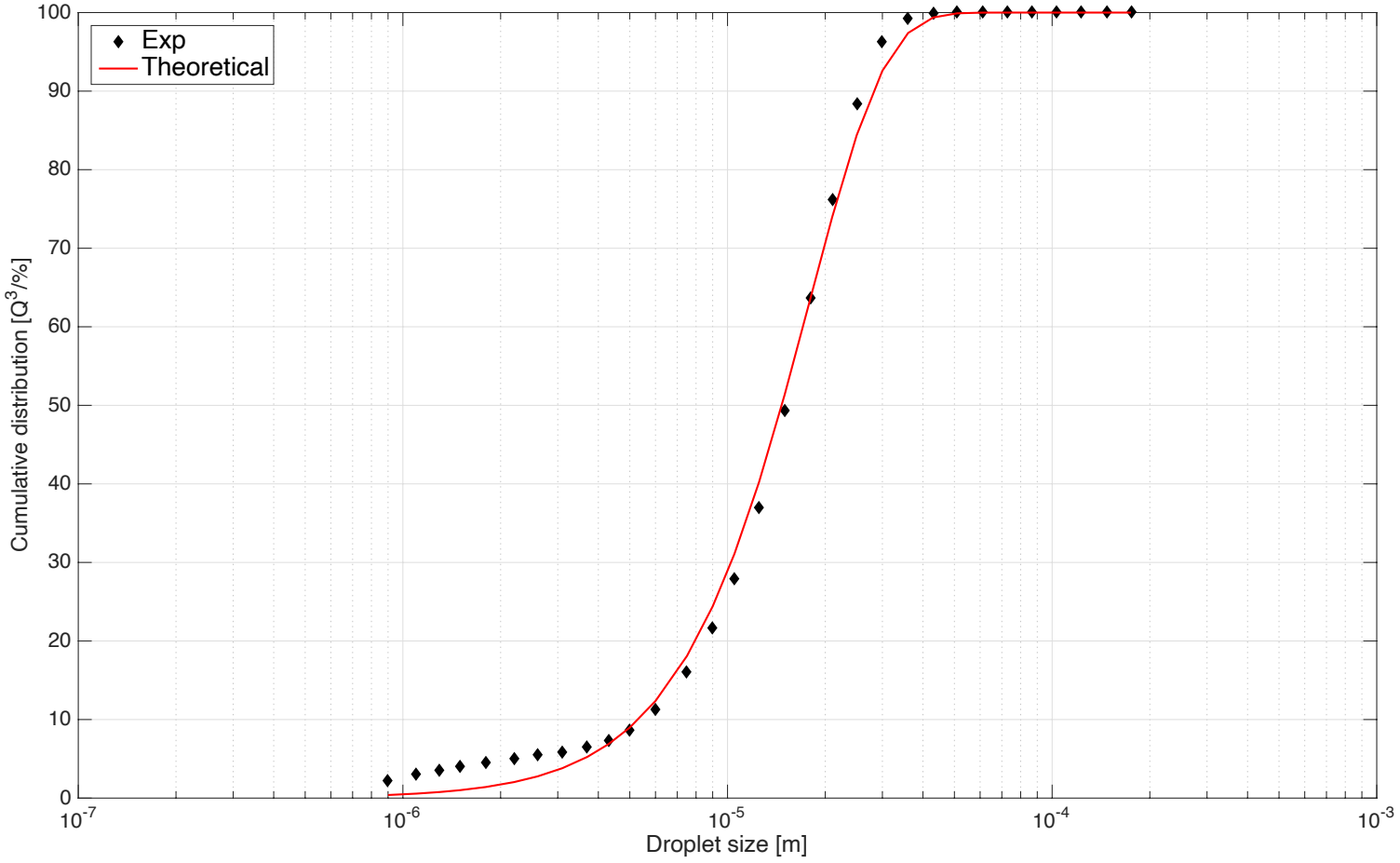
Piping system	Pipe diameter [mm]	Liquid (oil and water) flow rate [kg/s]	Air flow rate [g/s]
Straight 0.5 [m]	38 – 15 – 12	0.007 – 0.014 – 0.028 – 0.083	20 – 25
Straight 1 [m]	38 – 15 – 12	0.007 – 0.014 – 0.028 – 0.083	20 – 25
Straight 1.5 [m]	38 -15	0.028 – 0.083	20 – 25
Straight 2.5 [m]	38	0.028 – 0.083	20 – 25
Straight 3 [m]	38	0.028 – 0.083	20 – 25
Straight 3.5 [m]	38	0.028 – 0.083	20 – 25
Straight 5 [m]	38	0.028 – 0.083	20 – 25
1x curve 90˚	38	0.007 – 0.028 – 0.083	20 – 25
2x curves 90˚	38	0.028 – 0.083	20 – 25

Methodology

Experimental phase:

- Description of the granulometry using the Rosin-Rammler (RR) distribution

$$Y = 1 - exp\left(\frac{-x}{x_0}\right)^n$$



Methodology

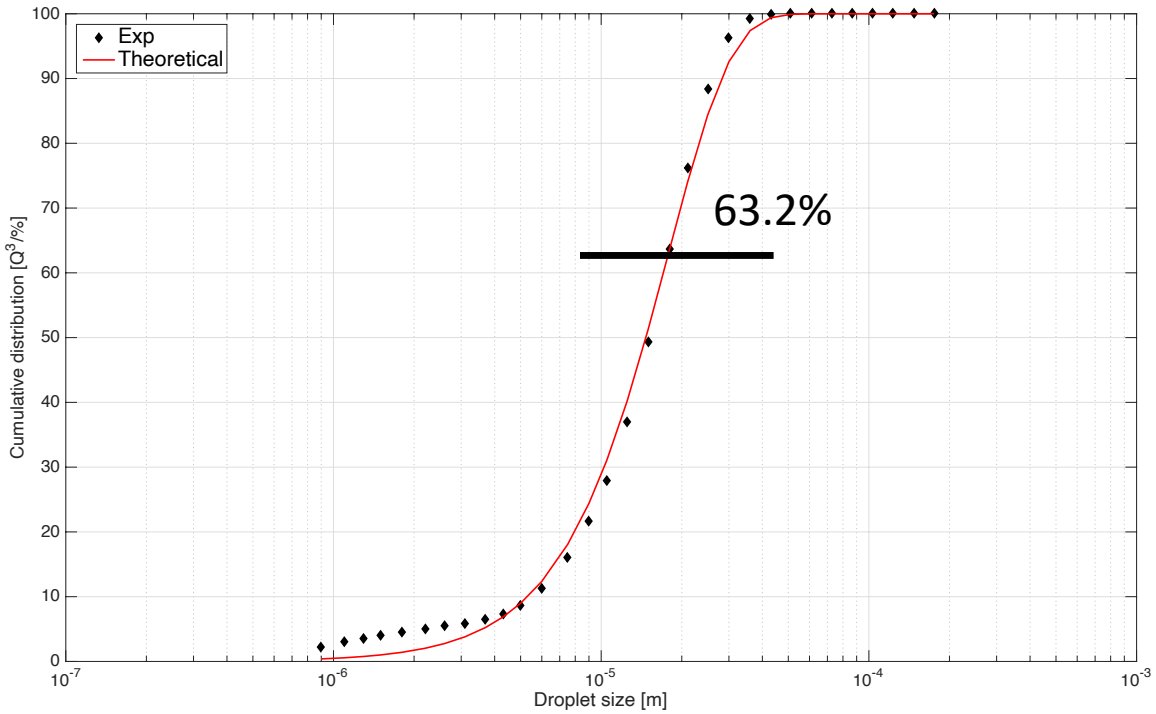
Experimental phase:

- Identification of distribution key parameter:
  - Mean diameter x_0
  - Spread parameter n

x_0 Corresponds to the diameter for which the 63.2% of particles are smaller

$$Y = 1 - exp(-1)^n = 0.632$$

$$n = ln\left(\frac{-\ln(Y)}{ln\left(\frac{x}{x_0}\right)}\right)$$



Methodology

Numerical Study

The inlet particle size distributions measured are used as boundary conditions for the numerical computations.

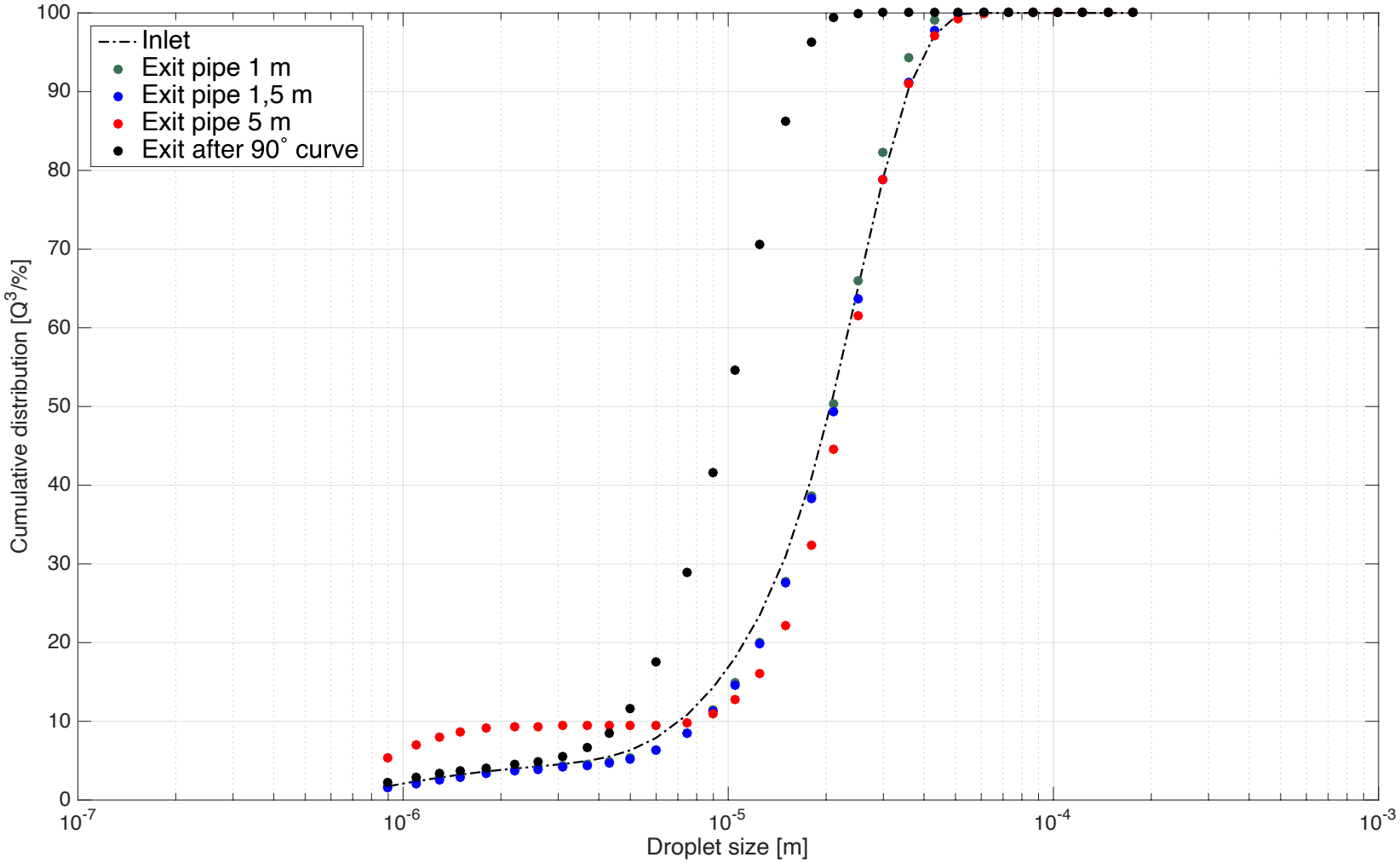
The outlet particle size distributions are used as validation data for the outcome of the CFD

Case	Straight pipe 0.5 [m] diameter 38 [mm]
Solver	Ansys Fluent
Turbulence model	$k - \varepsilon$ Realizable
Turbulence multiphase model	Dispersed
Discrete phase	DPM and DDPM
Inlet BC	Velocity magnitude of continuous phase
Discrete phase wall BC	Wall - film
Continuous phase time	Steady
Discrete phase time	Transient

Results

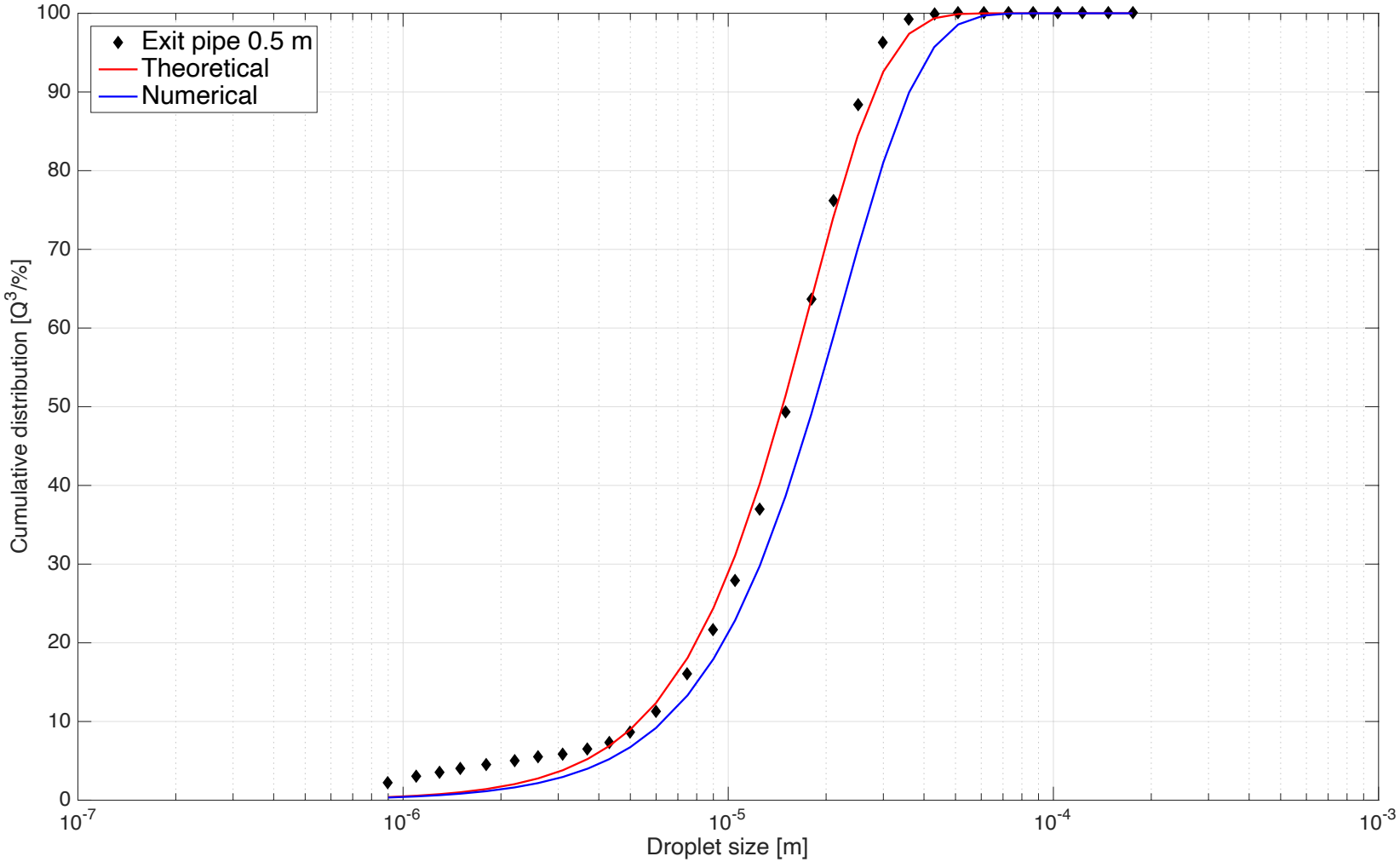
Experimental analysis:
The straight pipes slightly impact the droplet size

The presence of a 90˚ curve reduces the size of the droplets



Results

Experimental and numerical results at the exit of the 0.5m straight pipe.
The numerical curve is obtained by using the mean diameter and the spread parameter resulting from the CFD to define the RR distribution.
A good prediction is shown:
The spread parameter presents a 5% difference with the experimental data.



Conclusions and Further Activities

Experimental capabilities outcomes:

- Straight pipe has slight impact on droplet size
- Presence of bends reduces the size of droplets
- The Rosin-Rammler distribution shows a good fit with the experimental results. This leads to the identification of the RR parameters x_o and n. Therefore, it is possible model the droplet distribution whit these parameters, and it can be used as BC and validation for the numerical analysis

Numerical outcomes:

- The experimental RR distribution is the BCs for the inlet of the DPM
- The potential of CFD in predicting the droplet size distributions is proven
- The ability to have a distribution at the exit of the pipe gives the possibility to predict droplet behavior for a complete circuit

Further activities:

- Simulation of a more complex circuit and explore different operating conditions
- Explore the possibility to predict in-flight conditions using simulations.

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Conference Director: Tristan Loraine
Publisher: London, UK: GCAQE (https://gcaqe.org)
Editors: Dieter Scholz, Susan Michaelis

Aircraft Cabin Air – Neurotoxicity: Update and in-Depth Analysis

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Abstract

Purpose: The major objective of this study was to explore for possible common abnormal quantitative EEG (qEEG) and Low-Resolution Electromagnetic Tomography (LORETA) measures in a self-selected population experiencing health problems related to cabin air contamination.

Methodology: The EEG was recorded from 19 scalp locations, according to the International 10–20 System, from 70 participants ranging in age from 25 to 67 years. The majority were pilots and flight attendants with 2 to 42 years flying experience who were still active or non-active for 6 months up to 22 years. A small group of the participants were either frequent flyers or ground crew. Individuals were recorded during eyes-closed (ECB) and eyes-opened (EOB) baselines. Each ECB recording was visually inspected and classified according to the percent time of alpha appearance and distribution across the scalp. QEEG analysis was performed, calculating global absolute and relative powers for the delta, theta, alpha and beta bands and inter- and intra-hemispheric amplitude asymmetries, coherences and phase lag. LORETA current sources were also computed from 1 to 30 Hz.

Findings: A comparative inter-individual study of the EEG, qEEG and LORETA resulted in identifying 4 distinct groups. Each participant could be assigned to a particular group based on their percent time of alpha appearance and distribution across the scalp in the ECB EEG and alpha band peak frequency source power distribution. Group 1 can be characterized by a dominant posterior alpha rhythm and shows a maximum alpha band peak frequency source power distribution at the right postcentral and right superior temporal areas. Group 2 can be characterized by a subdominant posterior alpha rhythm and shows a maximum alpha band peak frequency source power distribution at the right postcentral and right superior temporal areas. Group 3 is represented by a rare or absent alpha presence and shows no qEEG or LORETA abnormal activity in the alpha band. Group 4 is represented by a diffuse alpha activity and a maximum alpha band peak frequency source power distribution in the anterior cingulate. Group 1 and 2 contains the largest number of subjects (82.9%), followed by group 3 with 11.4% of the subjects and group 4 with 5.7% of the subjects.

Discussion: These results raise a lot of questions that can be summarized under two main headings; where do these results come from and what effect can they have? Subjects exposed to aircraft cabin air can experience a varied number of symptoms. This research focuses on how the affected cortical areas may contribute to several of these symp-

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Related presentation: https://doi.org/10.5281/zenodo.4730412
Review process: Editorial review. The corresponding author is marked with *.
Previous presentation: Preliminary results on 30 subject where presented at the *Aircraft Cabin Air International Conference* 2019. London, UK: GCAQE. Available from: https://doi.org/10.5281/zenodo.4464526

toms. For this we look at three major brain systems or networks: cognitive brain networks, central vestibular system and language system. First, the areas with the maximum source power distribution of group 1, 2 and 4 belong to the three core cognitive brain networks. From this viewpoint we can expect cognitive dysfunctions that can vary according which areas and the number of areas that are affected in these networks. Secondly, the areas with the maximum source power distribution of group 1 and 2 are part of the central vestibular system in the non-dominant right-hemisphere. This not only means that balance issues can arise but also high-level cortical dysfunctions involving spatial cognition, including self-body perception, verticality perception, orientation, navigation and spatial memory. Thirdly, when looking at the language system and the results we would not expect any language related symptoms since language is in the dominant left-hemisphere for the majority of people, even in left-handed people. Research has shown that handedness determined by questionnaires are not a reliable indicator to determine the laterality of language and that language representation may be best considered as continuous rather than dichotomous. MRI DTI tractography studies have demonstrated that mapping cortical pathways is a better, non-invasive method, to determine laterality of language and has shown that language can also be bilateral; either bilateral left dominant or symmetrical. In these latter cases we can expect language reception and understanding dysfunctions for subjects in group 1 and 2. In summary this can help to explain the variability of symptoms across subjects which depends not only on the number of areas affected but also on the laterality of language and vestibular system. To try and answer where these results come from a search of literature related to the cholinergic system was conducted, since it has been establish by many authors that exposure to organophosphates, which affect the cholinergic system, are present in aircraft cabin air. Many older experimental studies have shown that acetylcholine modulates the alpha rhythm. In small doses the frequency and amplitude of alpha increase, while a large dose suppresses the alpha activity. Studies on accidental exposure of organophosphate based pesticides have shown that in the acute phase acetylcholine in the blood is increased and that the EEG shows an absence of alpha activity. In the recovery phase the blood level of acetylcholine decreases to normal levels while a gradual return of alpha activity is observed. These findings are consistent with the qEEG results showing variation in alpha power and frequency, and the presence of or absence of abnormal current source density is related to the peak alpha frequency. Other studies on the distribution of cholinergic components seem to indicate a relationship between maximum regional distribution and maximum alpha band peak frequency source power distribution. Histochemical studies illustrates that the maximal regional distribution of acetylcholinesterase (AchE) corresponds to the maximum source power in group 1 and 2. A recent [18F]FEOBV PET tracer study illustrates that the maximal regional distribution of the vesicular acetylcholine transporter (VAChT) corresponds to the maximum source power in group 4. Further, a clinical example of a frequent flyer seems to indicate that continued exposure over a period of 6 years leads to changes in the EEG, qEEG and LORETA. Initially this subject showed characteristics typical of group 1 and later on characteristics of group 3.

Significance: These results in combination with other studies provide support for biological probability of cholinergic dysfunction due to exposure of organophosphates leading to dose dependent neurophysiological changes consistent with current findings and related cognitive, language and vestibular dysfunctions.

Research Limitations: In spite of the fact that this study presents interesting findings consistent with other research into the cholinergic system and its dysfunctions, it has its limitations. Despite the fact that it suggests a possible dose dependent relationship, there is the lack of available data on the levels to which each member of this population was exposed. In order to further explain the variability of symptoms additional analysis of the data is needed to relate the nature and degree of symptoms to the extent of areas affected for each individual. This will however have its limitations due to a lack of reliable information on the laterality of language and vestibular system.

Keywords

EEG, QEEG, LORETA, acetylcholine, acetylcholinesterase, vesicular, transporter, cholinergic system, neurotransmission

List of Symbols

Ach	Acetylcholine
AchE	Acetylcholinesterase
DTI	Diffusion Tensor Imaging
ECB	Eyes-Closed Baseline
EEG	Electroencephalography
EOB	Eyes-Opened Baseline
MRI	Magnetic Resonance Imaging
LORETA	Low-Resolution Electromagnetic Tomography
QEEG	Quantified Electroencephalography
VAChT	Vesicular acetylcholine transporter
[18F]FEOBV	18F-fluoroethoxybenzovesamicol



Aircraft Cabin Air – Neurotoxicity:

Update and in-Depth Analysis

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Lab of Neurophysiology | qEEG – ERP

az sint-jan brugge-oostende av – campus Henri Serruys, Belgium

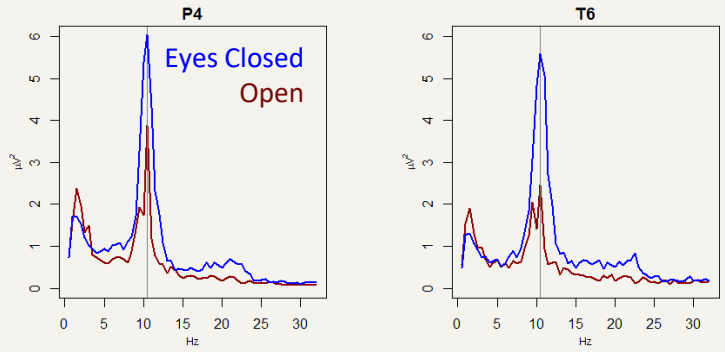


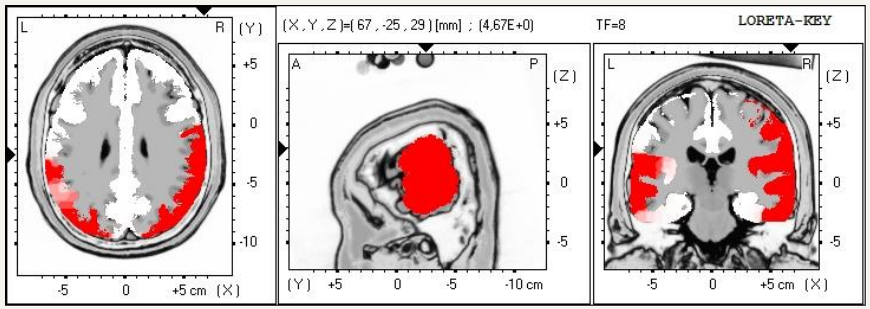
Neurophysiology

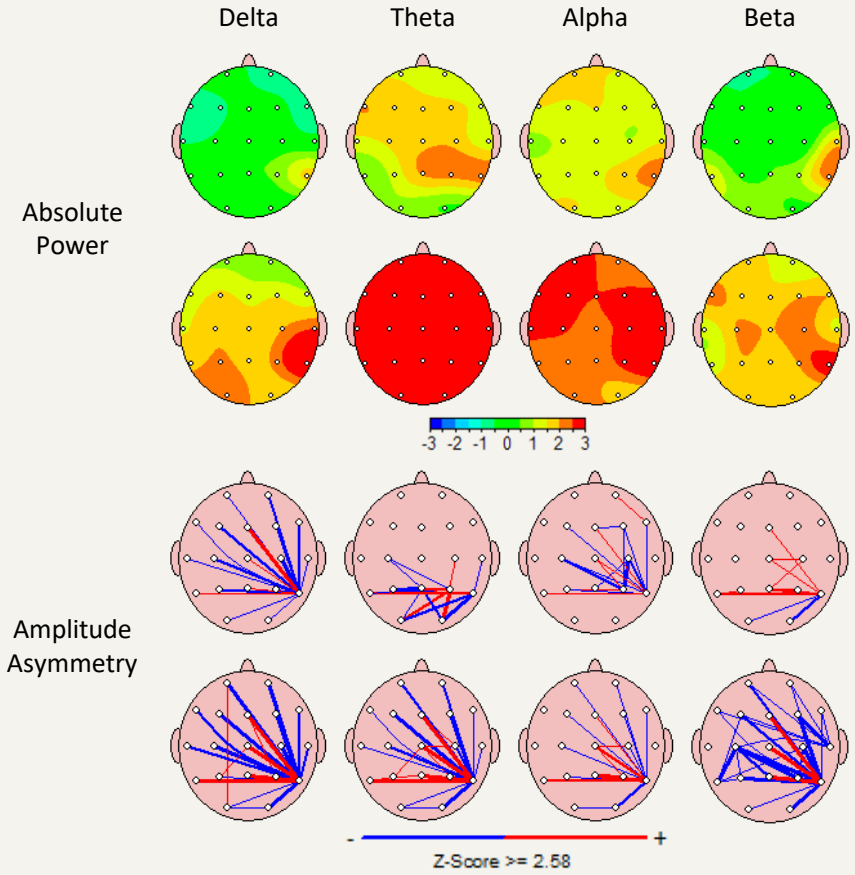
qEEG – ERP - EP

Neurophysiology

- qEEG









Preliminary Results

Total subjects: 70

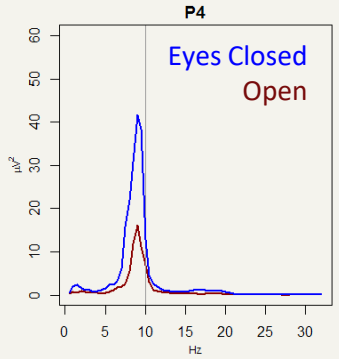


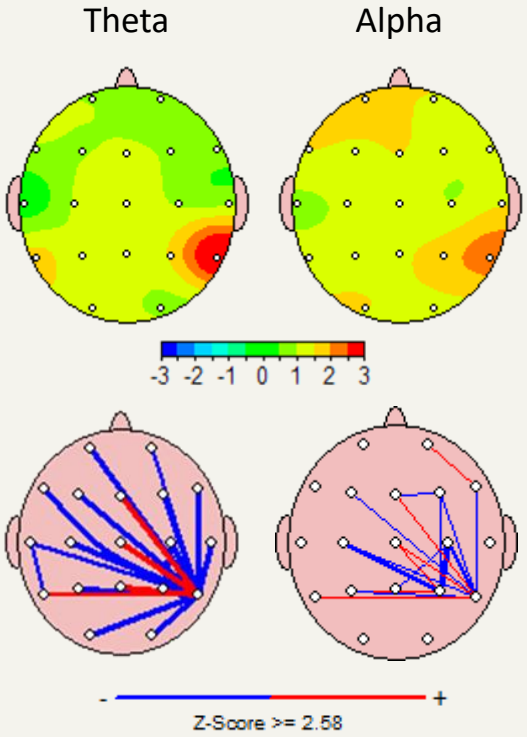
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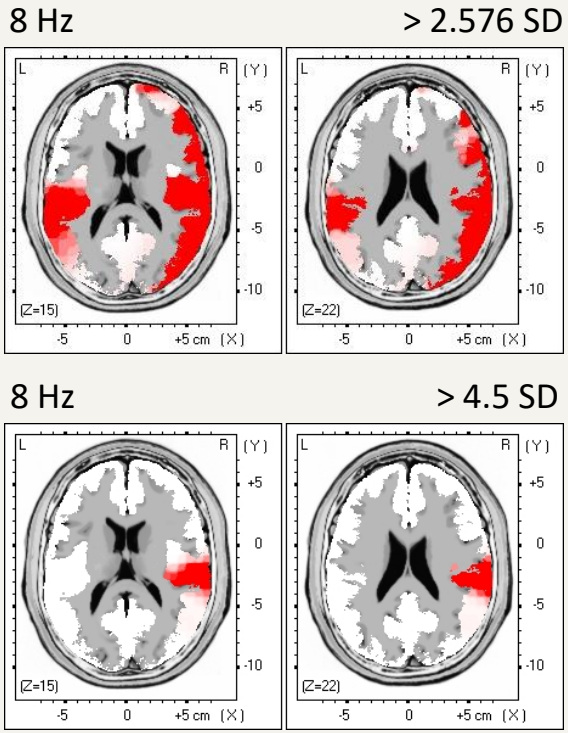
- Subjects
  - 70
  - Pilots, Flight Attendants
    Frequent Flyers, Ground Crew
  - 25-67 years of age, average 48 years (± 10.5)
  - 2-42 years of flying
  - Active or
    Non-active for 6 months – 22 years

Group 1

Total subjects: 37 of 70

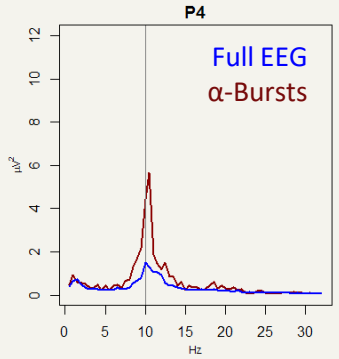


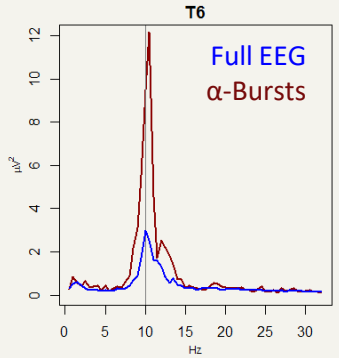




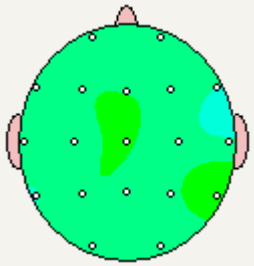
Group 2

Total subjects: 21 of 70

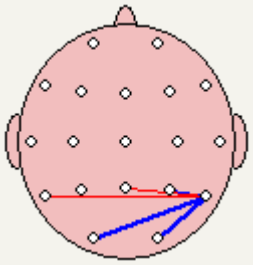




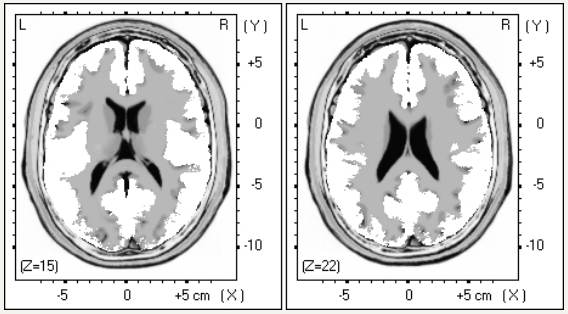
11 Hz

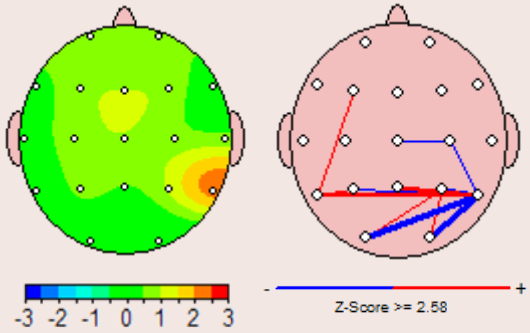


Alpha

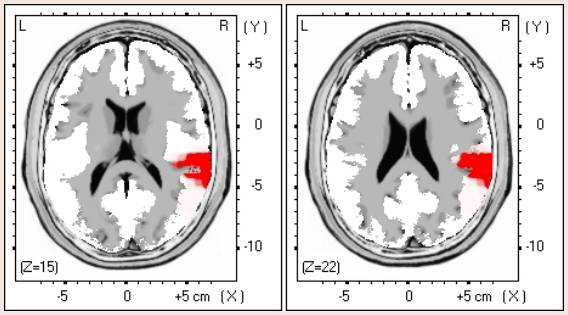


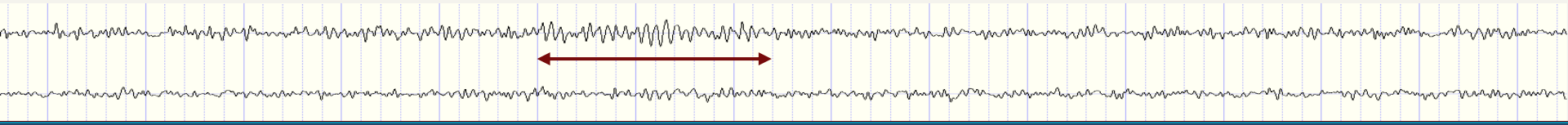
11 Hz > 1.960 SD





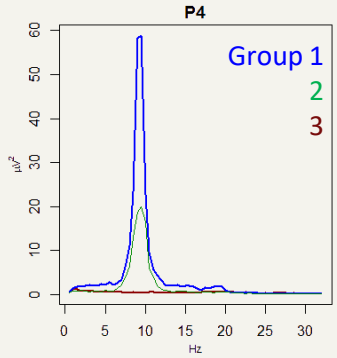
Alpha Burst > 2.576 SD

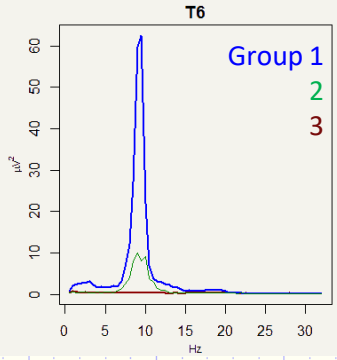


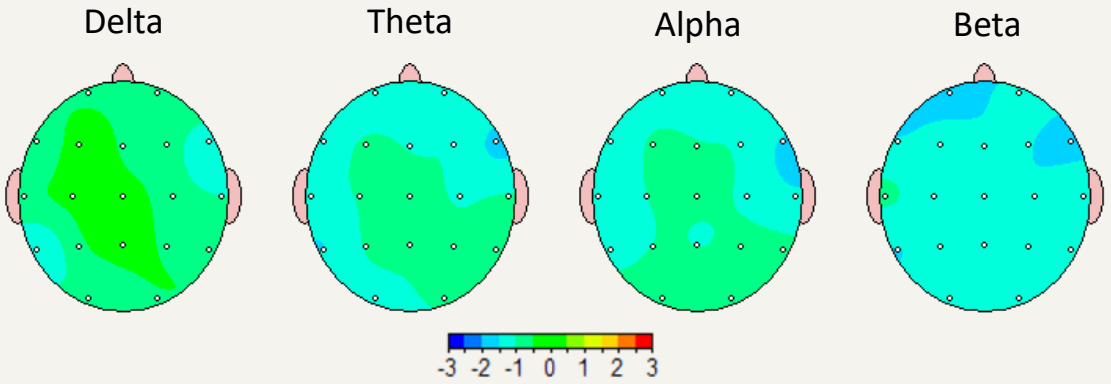


Group 3

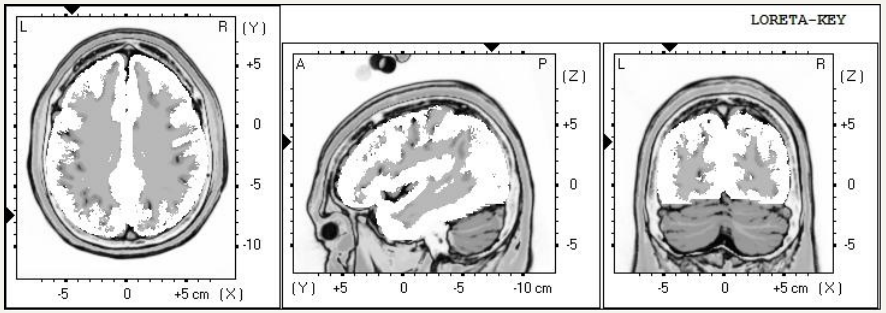
Total subjects: 8 of 70

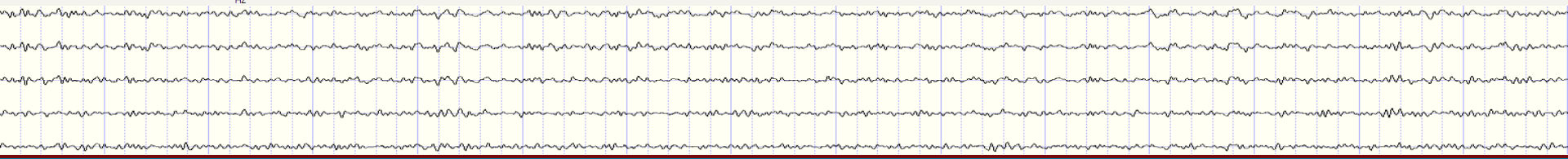






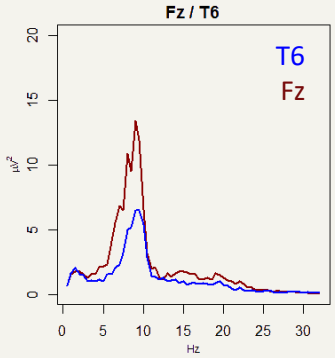
> 1.960 SD

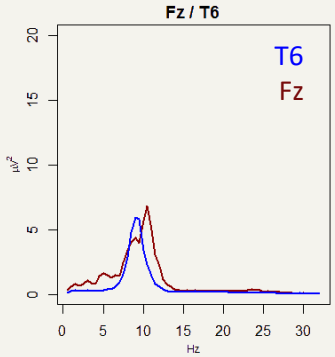




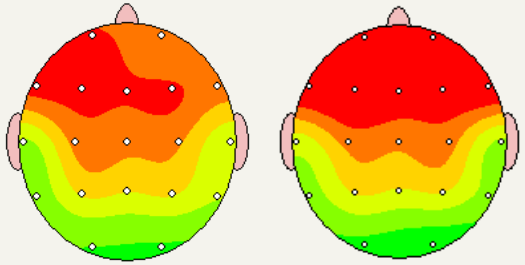
Group 4

Total subjects: 4 of 70

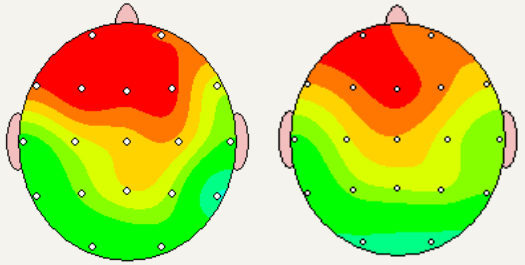




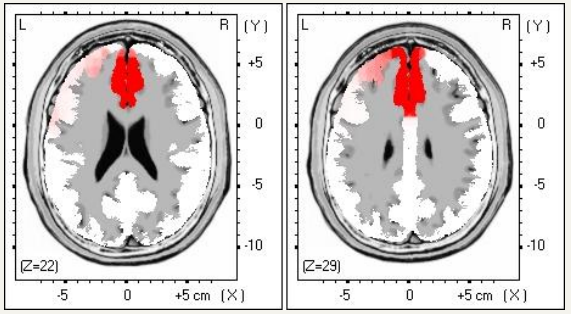
Beta 1 12 Hz



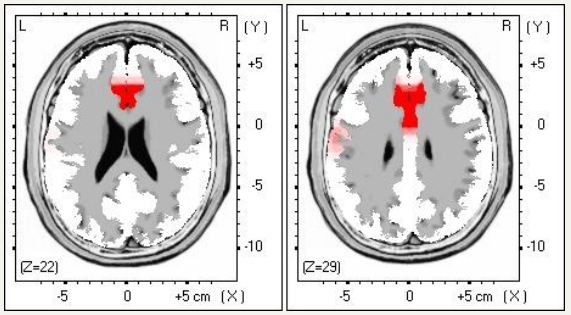
Alpha 11 Hz

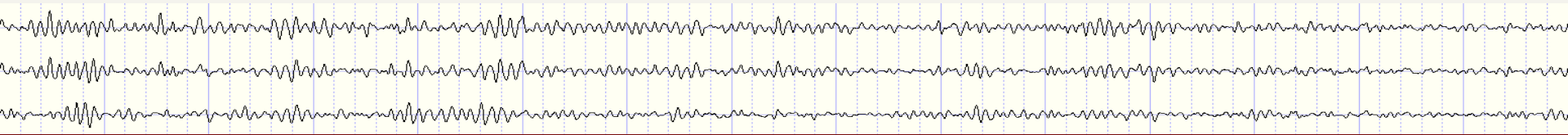


12 Hz > 2.576 SD



11 Hz > 2.576 SD





Group Distribution

Total subjects: 70

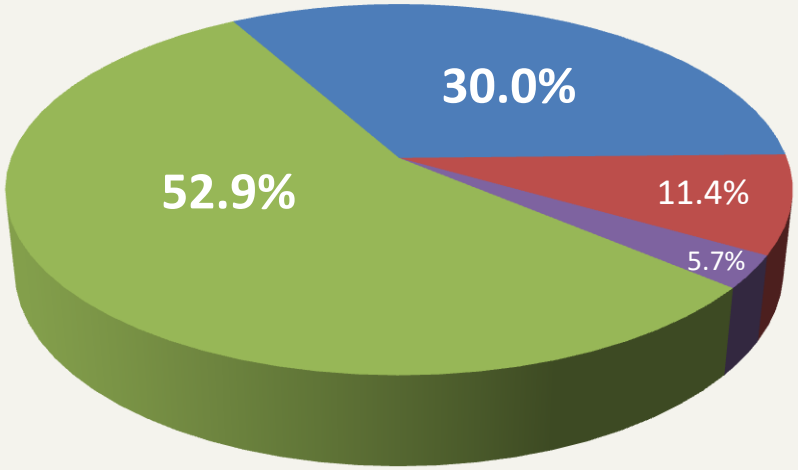
Group 1

- **Dominant** Alpha
- R-Post-central, R-Superior Temporal
- Peak Frequency: 7-14 Hz
- Pilot, Flight Attendant
  Frequent Flyer, Ground Crew

Group 2

- **Subdominant** Alpha
- R-Post-central, R-Superior Temporal
- Peak Frequency: 8-12 Hz
- Pilot, Flight Attendant
  Frequent Flyer, Ground Crew

52.9%
30.0%
82.9%
11.4%
5.7%



Group 3

- **Rare or absent** Alpha
- Pilot, Flight Attendant
  Frequent Flyer, Ground Crew

Group 4

- **Diffuse** Alpha
- Anterior Cingulate
- Peak frequency: 9-12 Hz
- Pilot, Flight Attendant

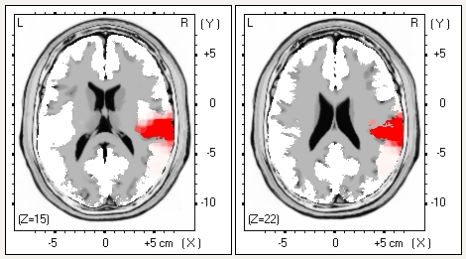


Connecting the dots

Location and Symptoms

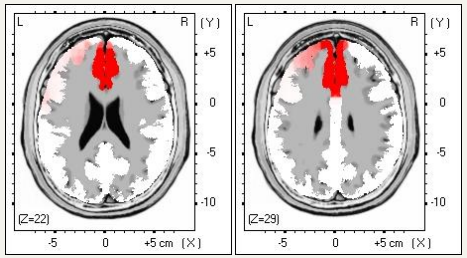
Cognitive (dys)functions

- Functions
  - Sensory integration
  - Attention
  - Executive functions



Group 1 - 2

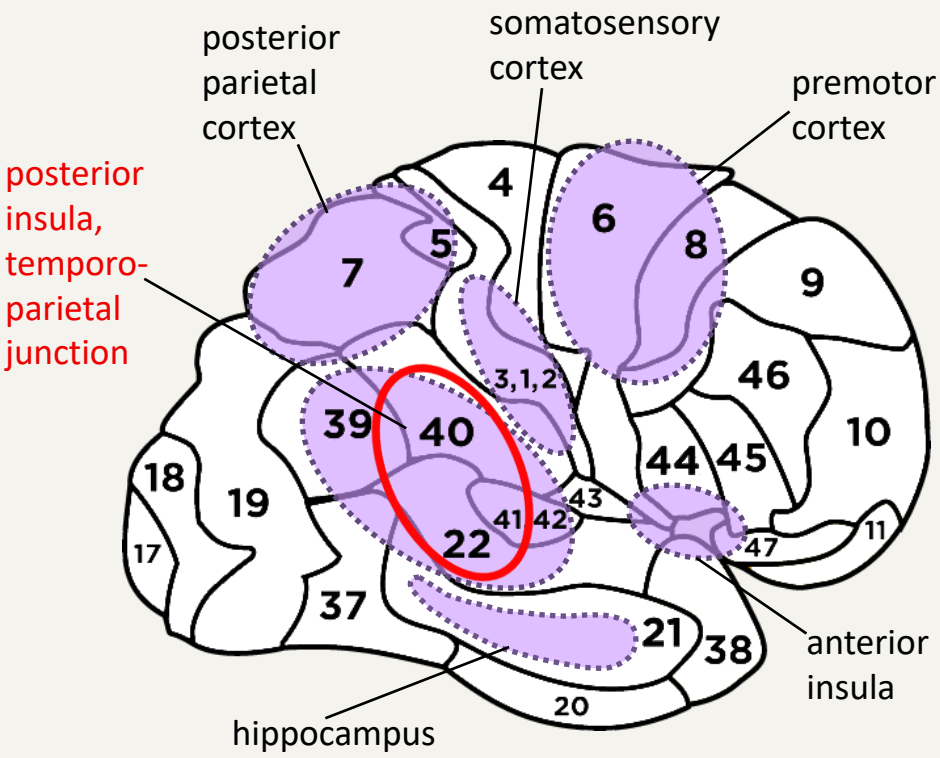
Group 4

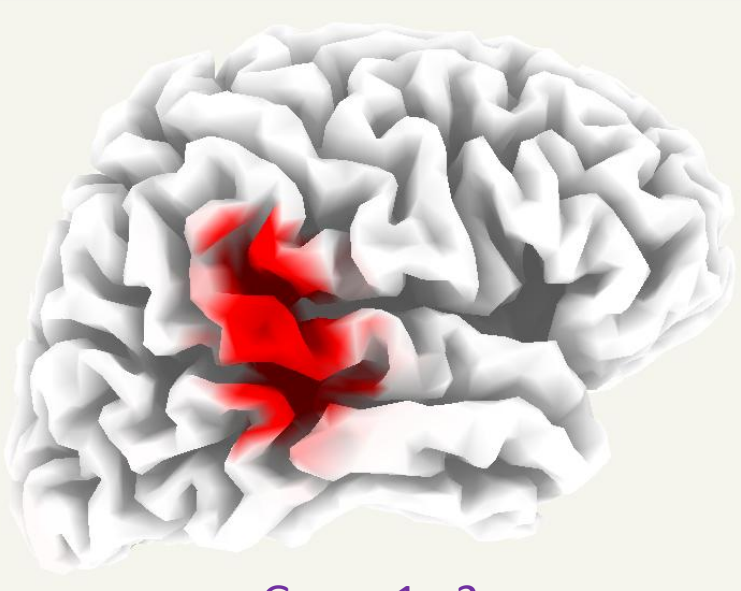


- Symptoms
  - Hypersensitivity
  - Attention problems
  - Losing train of thought
  - Unable to multitask
  - Trouble following conversations
  - Difficulty remembering steps in a multi-step process
  - Slow processing

Location and Symptoms

Central Vestibular System





Group 1 - 2

Location and Symptoms

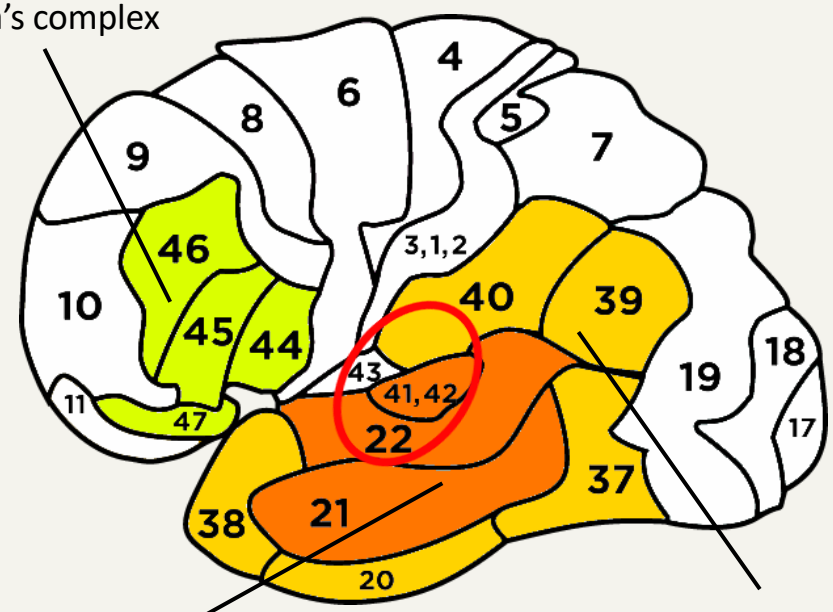
Language System

Lateralisation Arcuate Fasciculus (AF)

Nbr	Lateralization AF	Impairment
1	strong left	None
2	bilateral left	Possibly
3	bilateral symmetrical	Possibly

language production and grammar

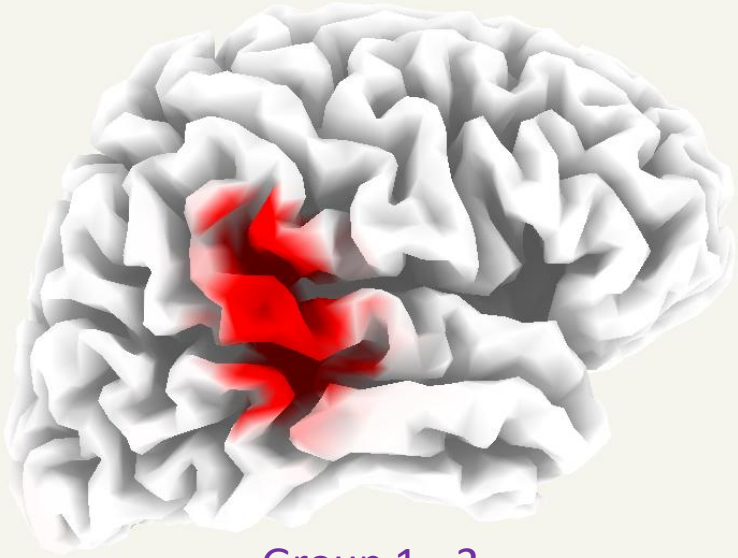
Broca's complex



core Wernicke's area

extended Wernicke's area

language reception and understanding



Group 1 - 2



Cholinergic System

- Organophoshates
  - Bleed Air
  - Desinsectants
  - Flame Retardants
- Carbamates
  - Desinsectants
- Metals
  - Aluminum



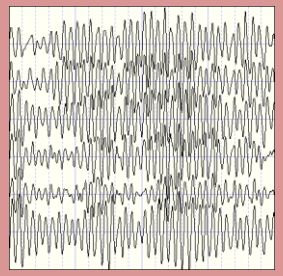
Acetylcholinesterase (AChE), Acetylcholine(ACh)



Acetylcholine and Alpha

S Dose

Frequency ↑
Amplitude ↑

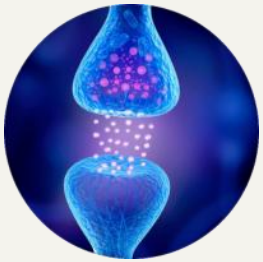


Blood ACh ↓

AchE ↑

Recovery

Experimental



ACh↑

Alpha dose dependency

Accidental



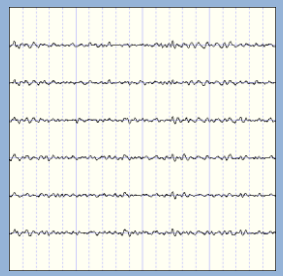
Acute phase

AchE ↓

Blood ACh↑

L Dose

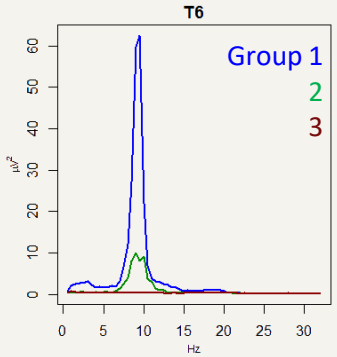
ALPHA

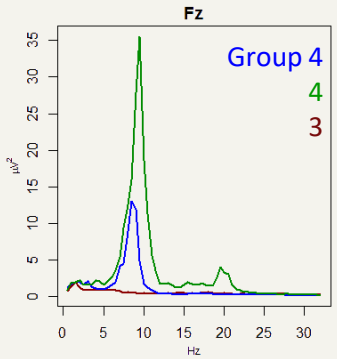


Acetylcholinesterase (AChE), Acetylcholine(ACh)

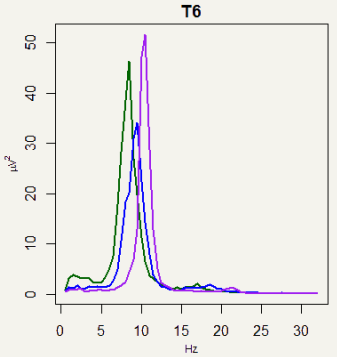
Acetylcholine and Alpha

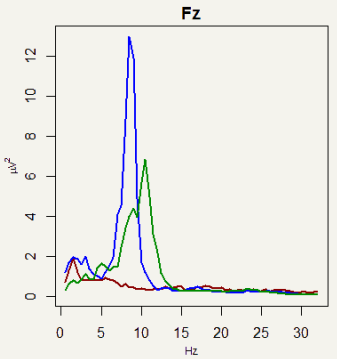
Power





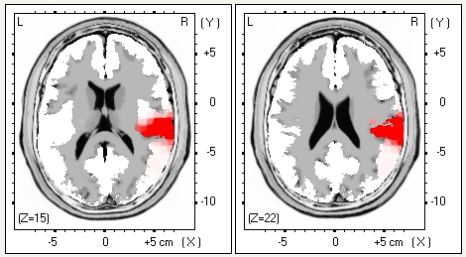
Frequency



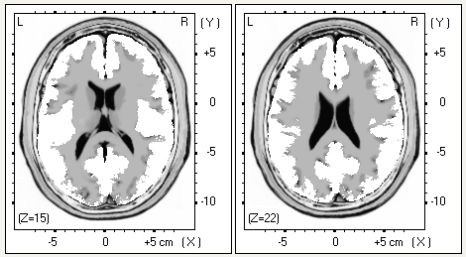


Pattern

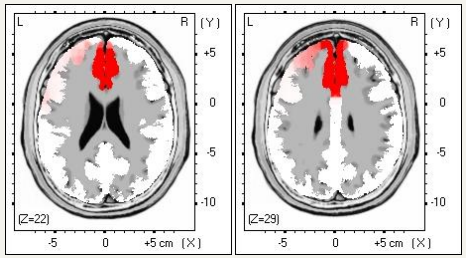
Group 1 - 2



Group 3



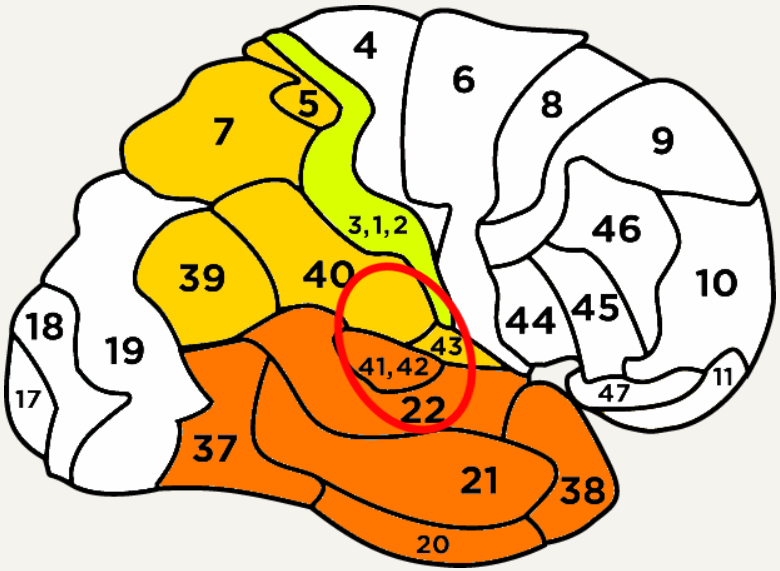
Group 4



Cholinergic System

Group 1 and 2

- Acetylcholinesterase (AChE)



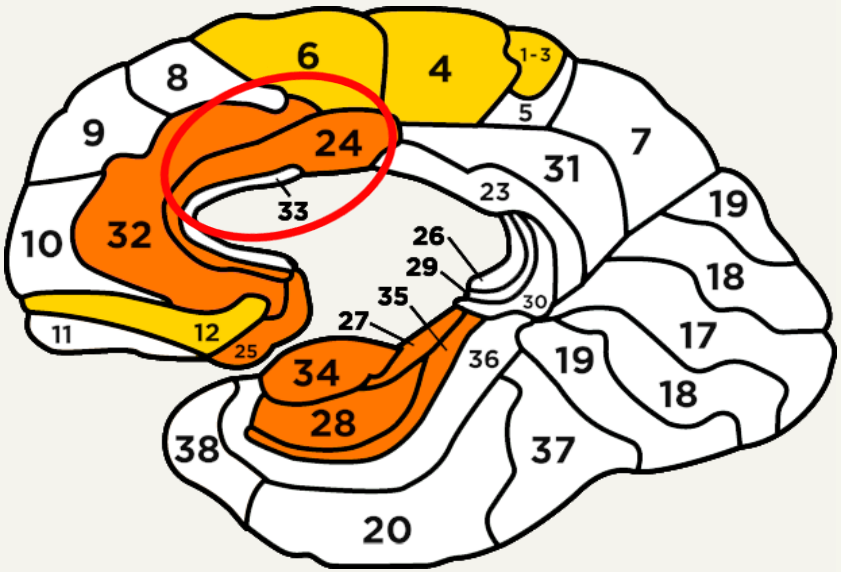


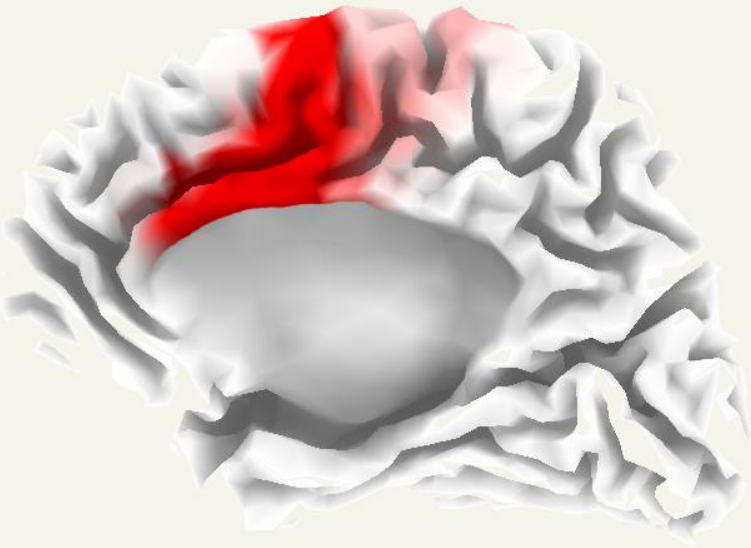
Histochemical: maximal regional distribution

Cholinergic System

Group 4

- Vesicular acetylcholine transporter (VAChT)

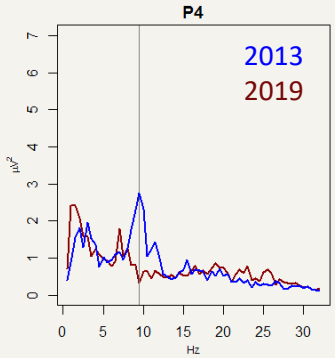


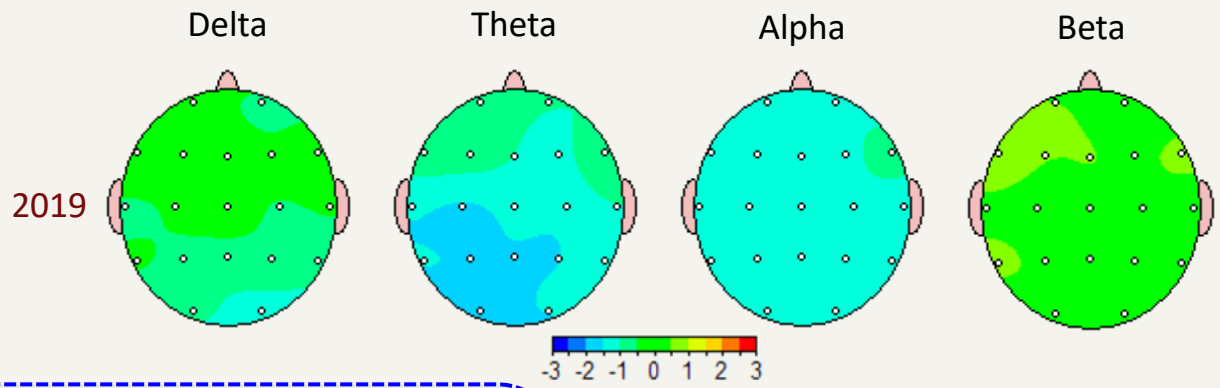


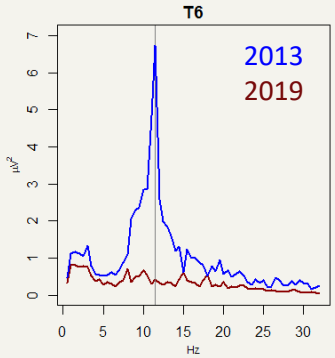
[18F]FEOBV PET tracer: maximal regional distribution

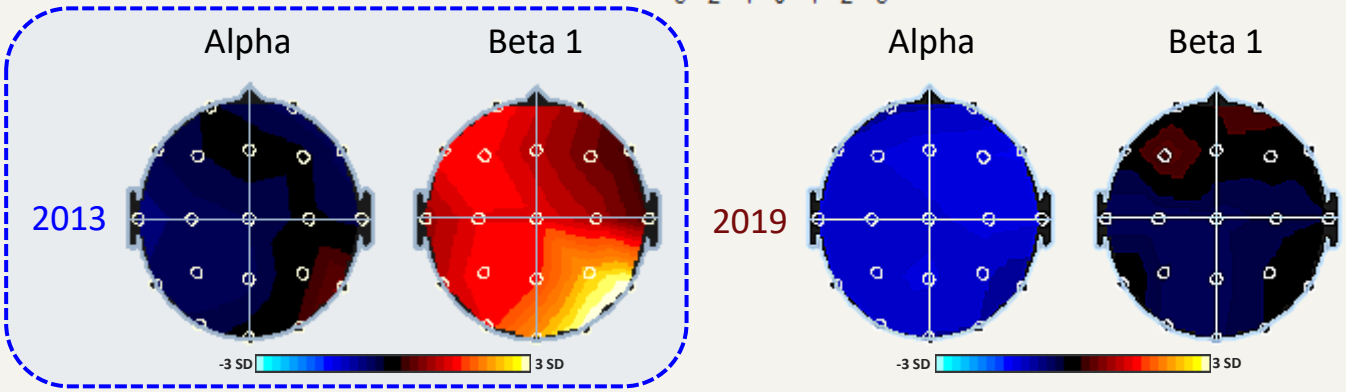
Exposure

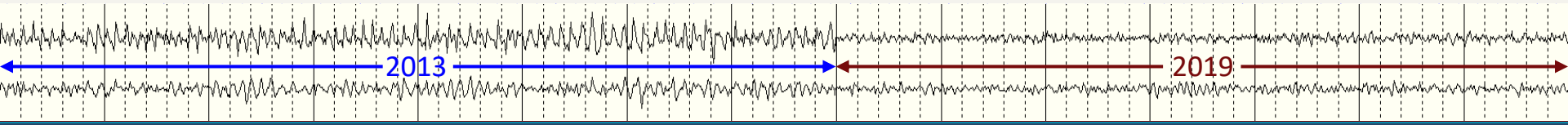
Example of continued exposure





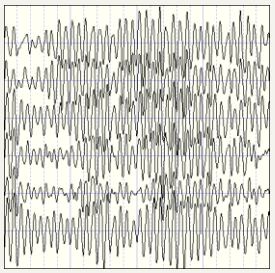








Aerotoxic Signature?

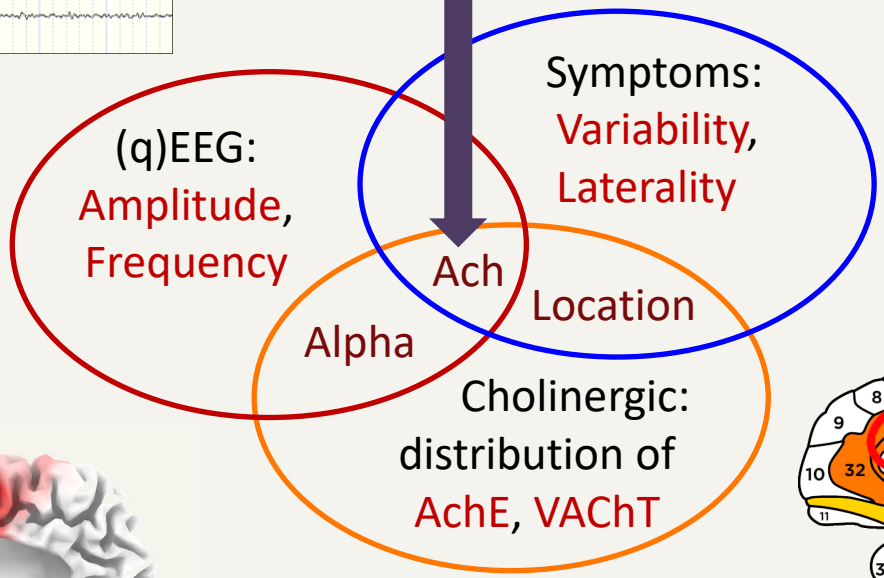


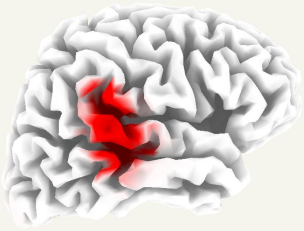


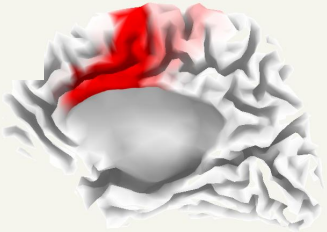
Organophosphates

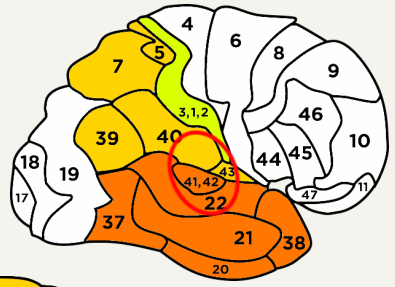
Dose

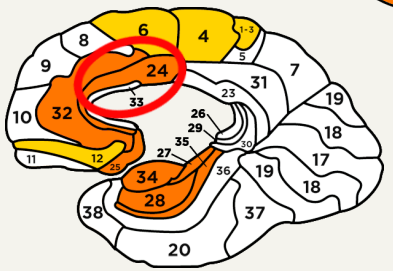
- Cognitive
- Language
- Vestibular











Acetylcholine (Ach)

Acetylcholinesterase (AChE), Vesicular acetylcholine transporter (VAChT)



Thank you for your attention

Daniel Dumalin | AerotoxBrain@proximus.be
Lab of Neurophysiology | qEEG – ERP
az sint-jan brugge-oostende av – campus Henri Serruys, Belgium

Two Sides of the Same Coin: Exposure to Lubricants from Aircraft Turbine Engines and Offshore Aeroderivative Gas Turbines

Why aviation and offshore oil and gas production share the same health risk from synthetic engine oils



International Aircraft Cabin Air Conference 2021
15 - 18 March 2021
https://www.aircraftcabinair.com

Halvor Erikstein
Organizational secretary

Certified Occupational Hygienist
SAFE – Norwegian Union of Energy Workers

While we are waiting for the sensors…..

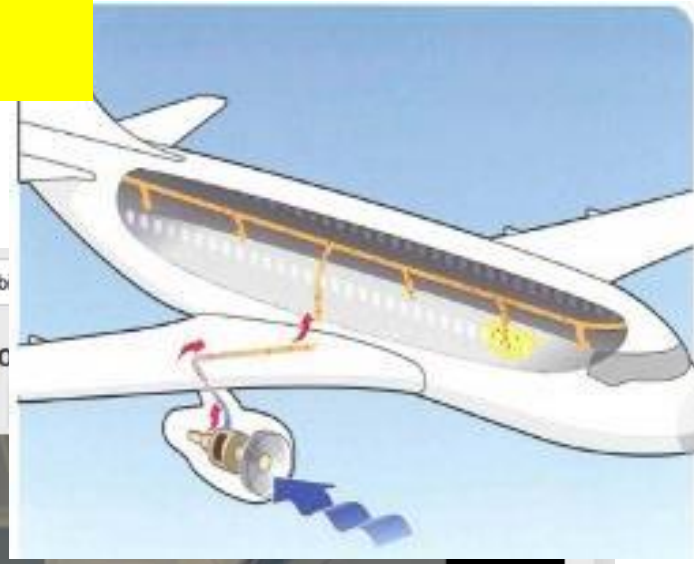


- In **1986**, a mining tradition dating back to 1911 ended: the use of canaries in coal mines to detect carbon monoxide and other toxic gases before they hurt humans. New plans from the government declared that the “electronic nose,” a detector with a digital reading, would replace the birds, according to the BBC.
- https://www.smithsonianmag.com/smart-news/story-real-canary-coal-mine-180961570/

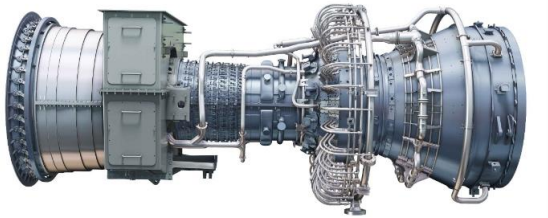
What do passengers, flight crew and oil workers have in common?



Turbine oil vapor mist







https://www.ge.com/power/gas/gas-turbines/lm2500



www.youtube.com/watch?v=AZqeA32Em2s
www.youtube.com/results?search_query=aerotoxic&page=1

Standard equipment:
3 turbines for power generators
2 turbines for pumps/compressors



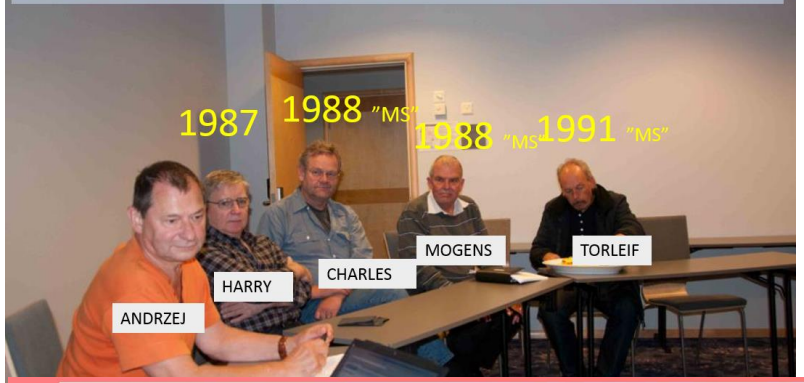
Asymmetric risk distribution

Who can stand it - and who can not stand it?

The employee takes all the health risk due to lack of knowledge. Those who set the requirements to the working environment and neglect knowledge and preventive measures, do not take any risk themselves, but consistently transfer all risk to the employee.



Det er ille å miste jobben fordi arbeidsoppgavene er tatt fra en -
Men det er verre å miste jobben fordi arbeidet har tatt helsa



Den virkelige verden for mange skadde



SKADD: Harry Stiegler Brevik jobbet ved turbinene på Statfjord A i Nordsjøen. I 1987 ble han alvorlig syk.
Foto: Asle Hansen

- Dattera mi har aldri sett en far uten helseproblemer

Slående likheter mellom skadde piloter og

http://www.dagbladet.no/nyheter/2008/05/08/534738.html

Same lubricants are used on aircraft turbines and aeroderivative turbines

- High exposure offshore from unmarked oil ventilation systems (vent).
- Absolute denial from oil companies (Statoil/Equinor of toxic effects from exposure)
- Aeroderivative gas turbines
  - OFFSHORE: Used on oil and gas production platforms
  - SHIPS: Used for propulsion and for electrical power production
  - POWERPLANTS: Used for electrical power production.



Could aviation and industries using aeroderivative turbins work together?



NEWS

GE Gas Turbine Chosen for New USN Vessel

The Constitution-class guided missile frigates will be the first U.S. Navy ships to be powered by GE Marine's LM2500+G4 gas turbine as part of a combined diesel electric and gas turbine propulsion system.

DEC 16, 2020

https://www.americanmachinist.com/news/article/21150622/ge-lm2500g4-gas-turbine-engines-chosen-for-new-usn-vessels-ge-marine

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MARINELINK

Shipbuilding Offshore Coastal/Inland Government Equipment Training Law & Regulations

GE Gas Turbine Powers First National Security Cutter

May 15, 2008



Bertholf is the first of class for the U.S. Coast Guard under its Deepwater Program.

GE Marine announces that its LM2500 marine aeroderivative gas turbine now powers the United States Coast Guard's first National Security Cutter, Bertholf. The cutter recently completed extensive sea trials and was delivered to the U.S. Coast Guard on May 8 by shipbuilder Northrop Grumman Shipbuilding (NGSB).The cutter's propulsion system consists of one LM2500 gas turbine in a COmbined Diesel And Gas turbine (CODAG) arrangement with two MTU 20V1163 diesel engines. The propulsion system was provided by MTU Detroit Diesel Corporation.

"During sea trials, the LM2500 gas turbine and the entire CODAG system were operated in a variety of speed settings. A four-hour, full power run was conducted while in CODAG mode with the gas turbine performing well at 29,500 shaft horsepower," said Brien Bolsinger, general manager, GE Marine, .

Bertholf is the first of class for the U.S. Coast Guard under its Deepwater Program. Built by NGSB at its shipyard, the 418-foot-long cutter with a 54-foot beam has a displacement of 4,300 tons. The CODAG propulsion system can propel the ship at speeds greater than 28 knots.

The delivery of Bertholf allows the Coast Guard's crew to move aboard the cutter and place it "In Commission Special" status. This status indicates that the vessel is entering a post-delivery period of approximately 22 to 24 months during which it will undergo crew training, operational evaluation and certification, and post delivery and post shakedown availabilities to ensure it meets all performance and operational requirements. A formal commissioning ceremony is scheduled on Coast Guard Day, August 4, 2008 in

The second National Security Cutter Waesche is currently under construction at NGSB's shipyard. The vessel will also be powered by the same LM2500-based CODAG propulsion system. The LM2500 gas turbines for these cutters were

https://www.marinelink.com/news/national-security-turbine327099



Norwegian navy

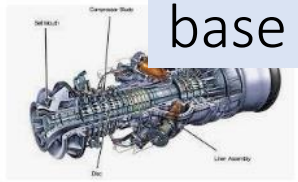
2 × BAZAN BRAVO 12V 4,5 MW diesel engine
1 × GE LM2500 21,5 MW gas turbin

https://no.wikipedia.org/wiki/KNM_%C2%ABFridtjof_Nansen%C2%BB

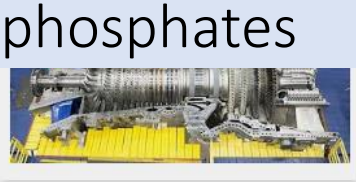
Synthetic oils with organophosphates are used both in aviation and on aeroderivative gas turbines
Check the manual for lubrication. If MIL SPEC 23699 - synthetic base oil with organophosphates

Google aeroderivative gas turbines

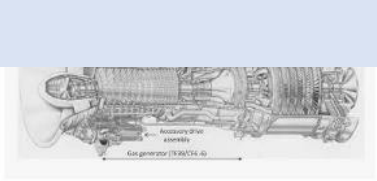

LM6000 Aeroderivative Gas Turbine | GE ...
ge.com


The Evolution of Highly Efficient Aero ...
williamson.edu

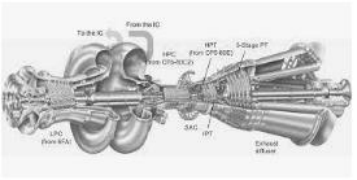

Gas turbine selection: Heavy frame or ...
turbomachinerymag.com


Heavy-Duty Gas Turbines | GE Power
ge.com


AERODERIVATIVES VERSUS RECIPS ...
turbomachinerymag.com


Aeroderivative Gas Turbine (Chapter 23 ...
cambridge.org


The Aeroderivative Gas Turbine Fleet in ...
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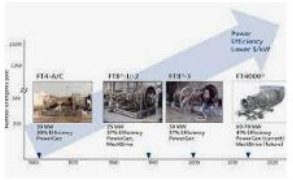

Aeroderivative Gas Turbine (Chapter 23 ...
cambridge.org


LMS100 Aeroderivative Gas Turbine | GE ...
ge.com

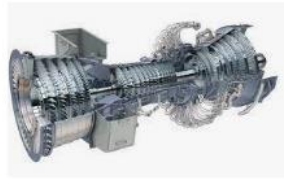

GE BETS ON AERODERIVATIVES ...
turbomachinerymag.com


Diesel & Gas Turbine Worldwide


GE's LM6000-PG & -PH Aeroderivative Gas ...


Aeroderivative Gas Turbines at PWPS


Aeroderivative Gas Turbine Repowering ...


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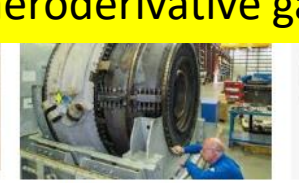

44-MW Aeroderivative Gas Turbine Model ...
powermag.com


SGT-A05 | Aeroderivative Gas Turbine ...
siemens.com



Why aeroderivative gas turbines make ...
powerengineeringint.com


Flexible Aero-derivative Gas Turbines ...
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AERODERIVATIVE GAS TURBINES ...
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in Aeroderivative Gas Turbines ...
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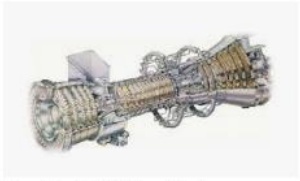

44-megawatt aeroderivative gas turbine ...
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LM9000 | Baker Hughes
bakerhughes.com

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Helicopters are using bleed air



Some lubricating oil manufactures have been renamed in recent years and oils has change name





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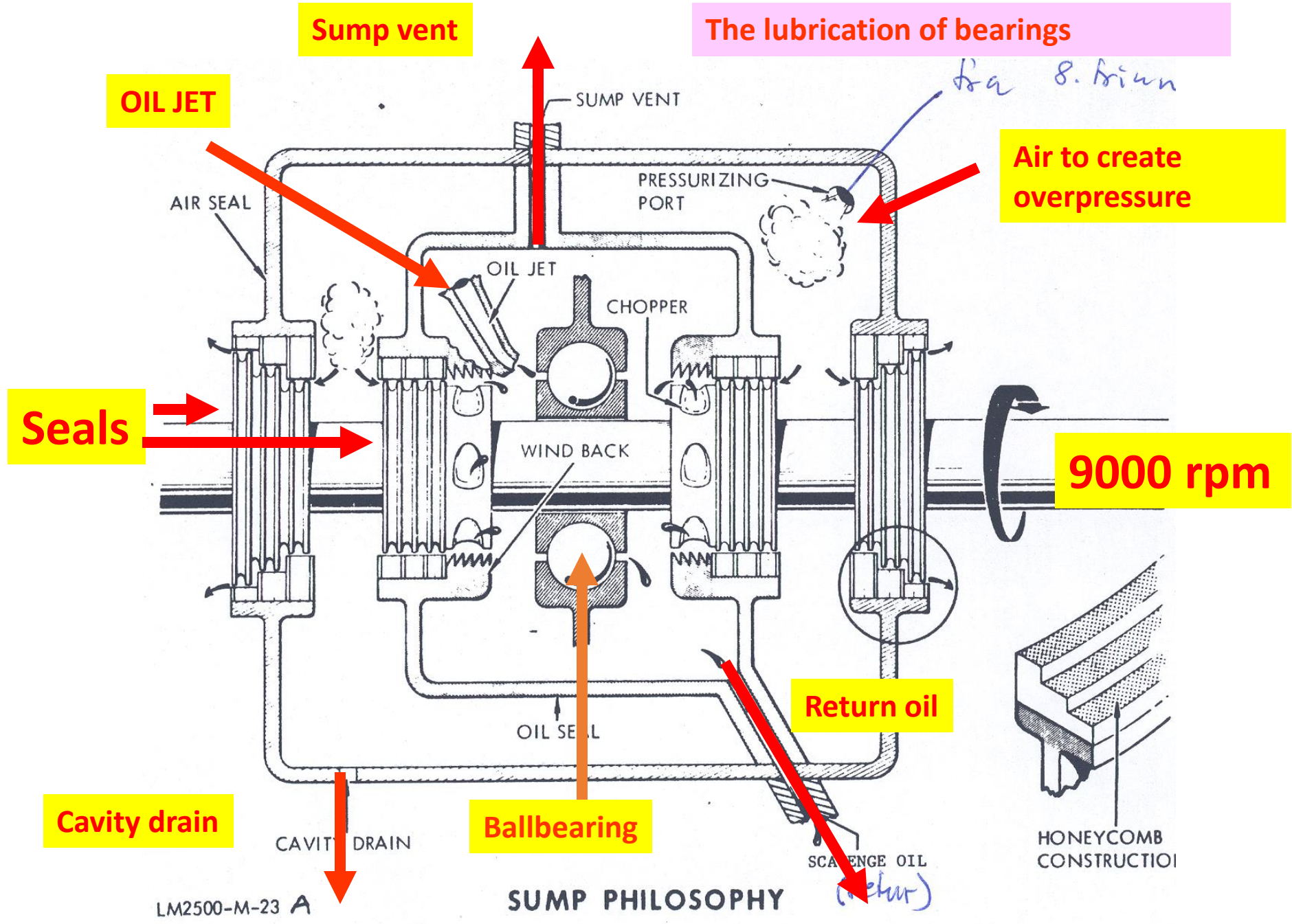
NYCO SYNTHETIC ESTERS & SPECIALTY LUBRICANTS





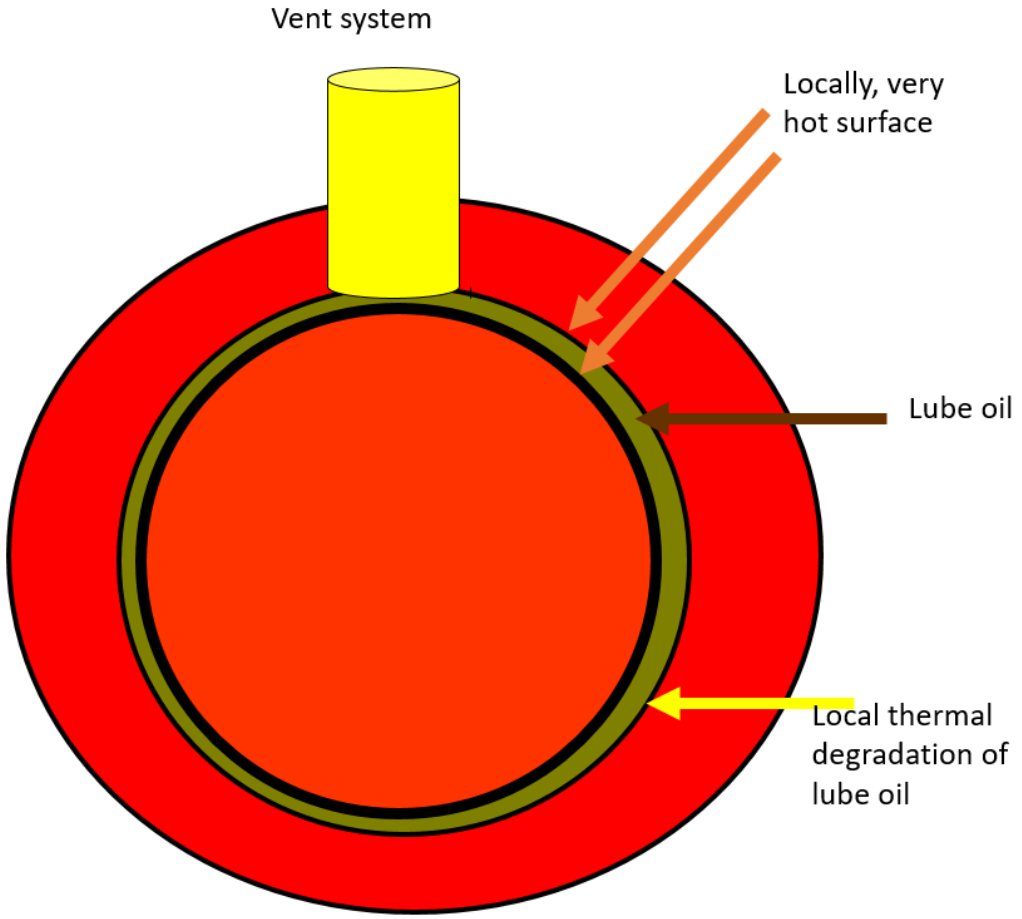
https://www.nyco-group.com/

The lubrication of bearings



Thermal degradation of lube oil

- Some areas may have temperatures exceeding 500 ^{o}C
- This temperature will create thermal decomposition of the oil components
- Some of degradation products will be much more volatile and be vented out into the sump vent.
- One must expect that new compounds will be created by different chemical reactions.

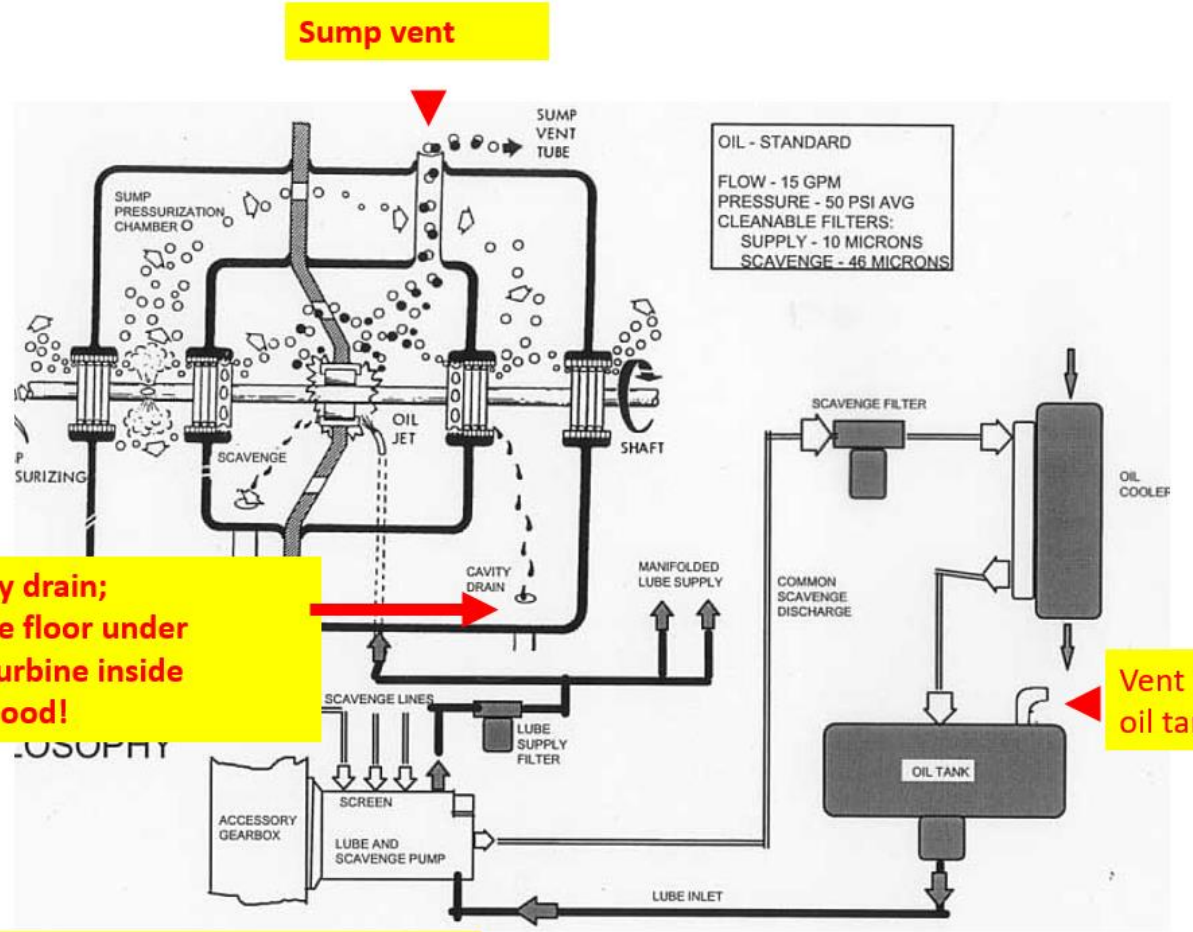


One of the major exposure source will be the oil vapor/oil mist from the oil vent system.







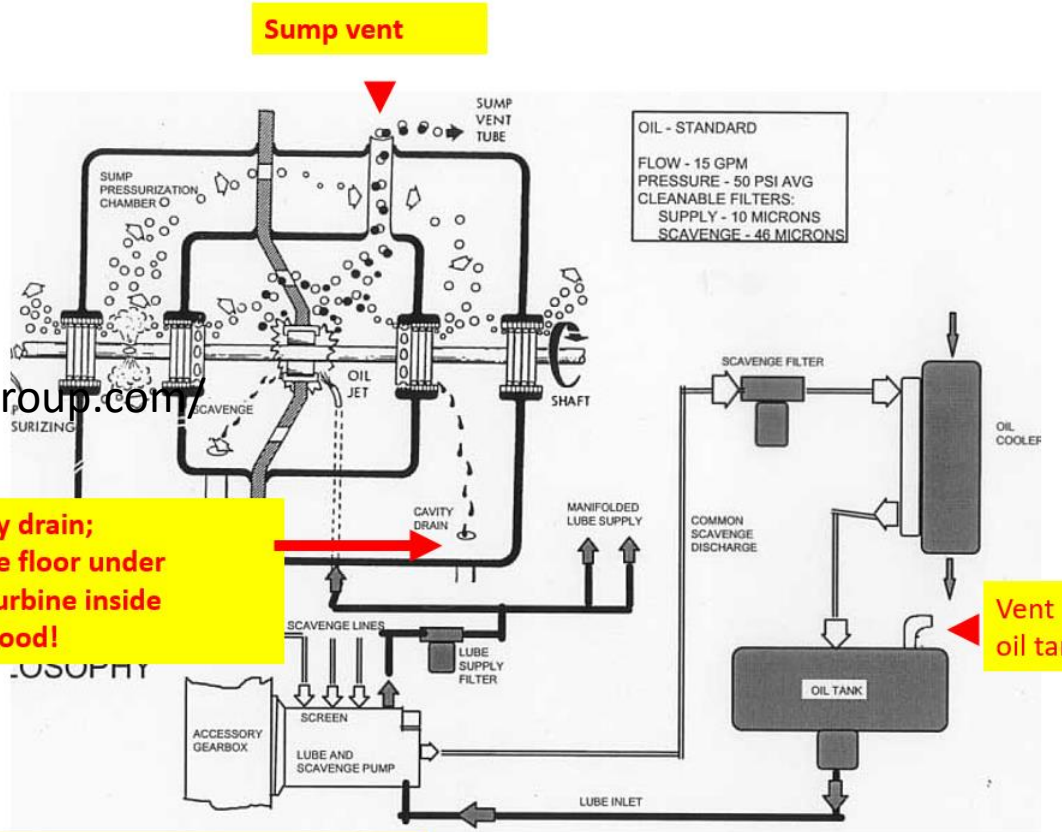






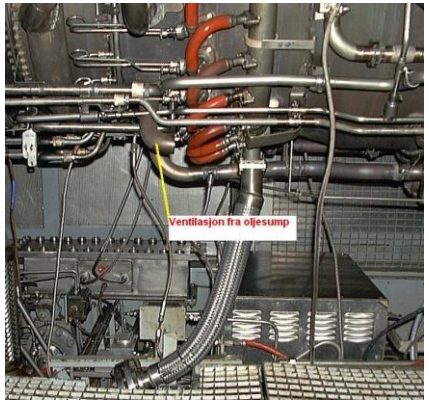
NO DATA – NO RISK ASSESSMENTS
DATA ON EMISSION SOURCES
Volume of emissions?
Chemical connections?
Composition?
Spread?
Surveys?
Risk assessments?
Health hazard?
Health monitoring?

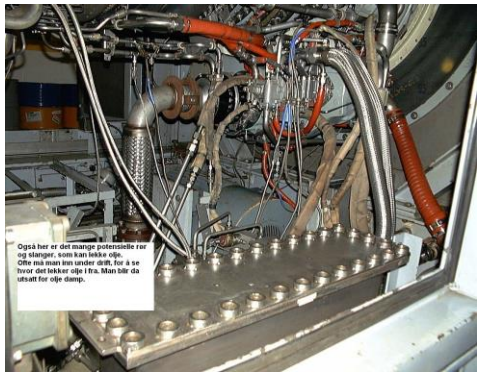
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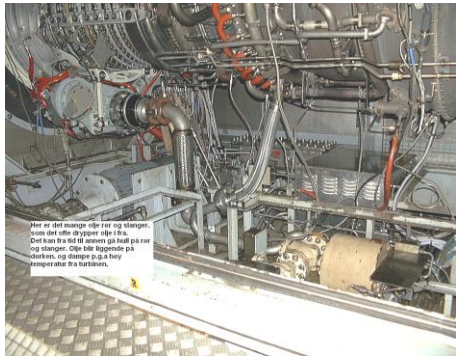


Turbine hoods and generator layout





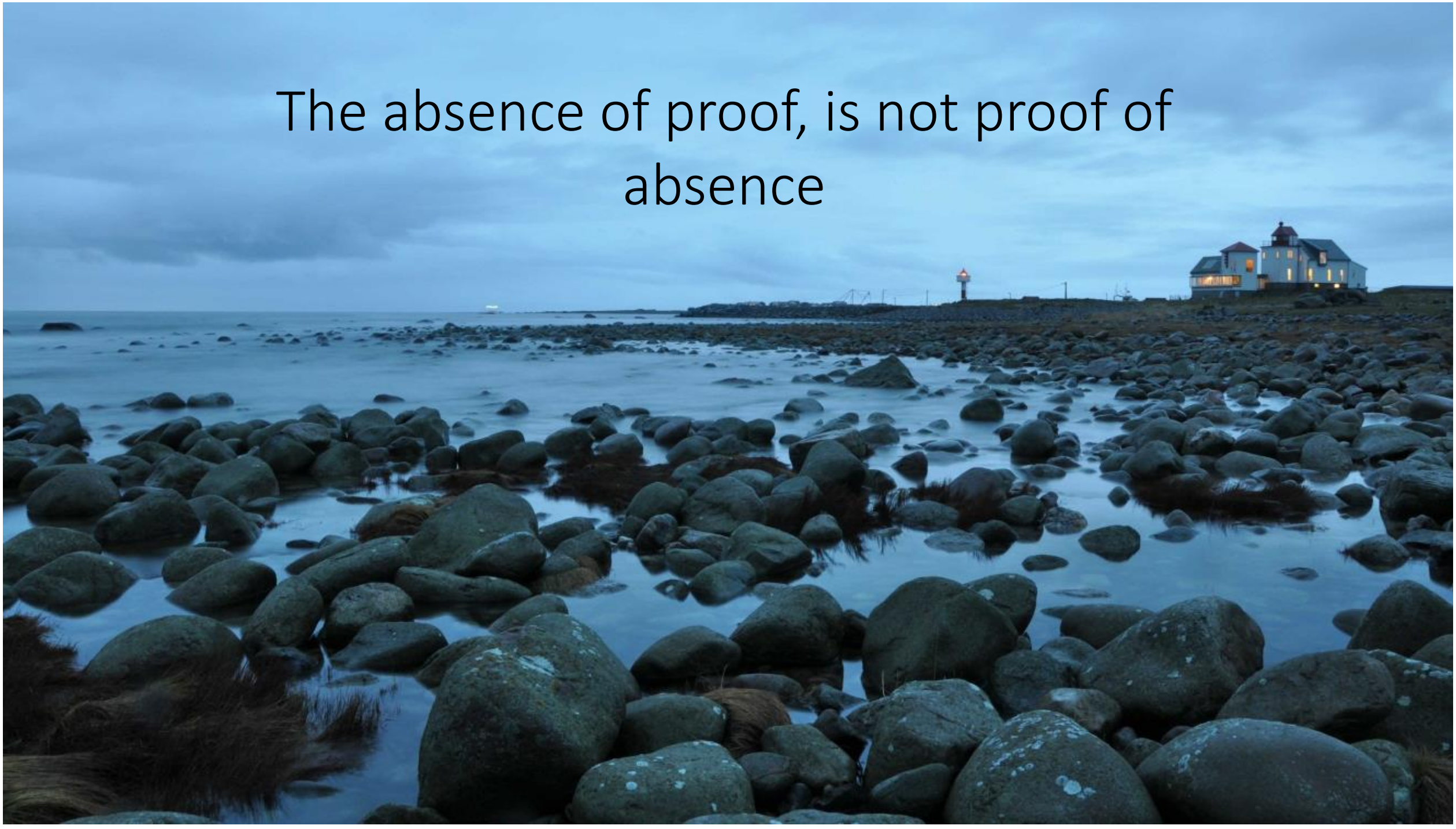




Toxic turbine oils and the industry

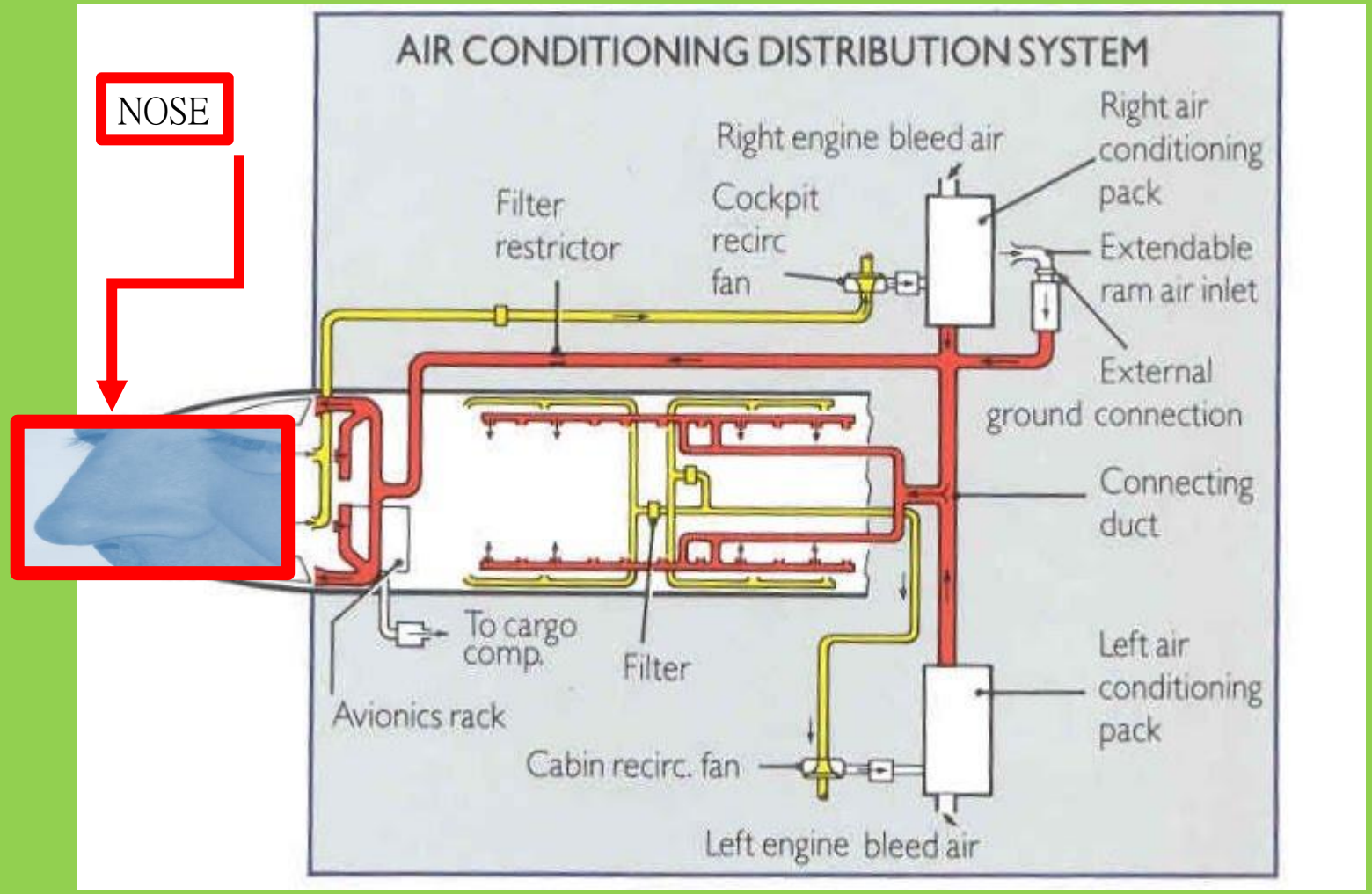


- Workes compensation – the burden of proof is on the sick workers.
- As long as the toxicant is not “known”, documented and health effects published and accepted as work related, the workers are denied any compensation.
- Statoil has changed name to Equinor – but that hasn’t changed their attitude to those who are sick from turbine oil exposure
- The strategy is so simple – just avoid to read the literature and do nothing don’t support any research


The absence of proof, is not proof of absence

The Nose to recognize and evaluate chemical exposure is absolutely unreliable!

Noxious **O**dor **S**urveillance **E**quipment (NOSE)

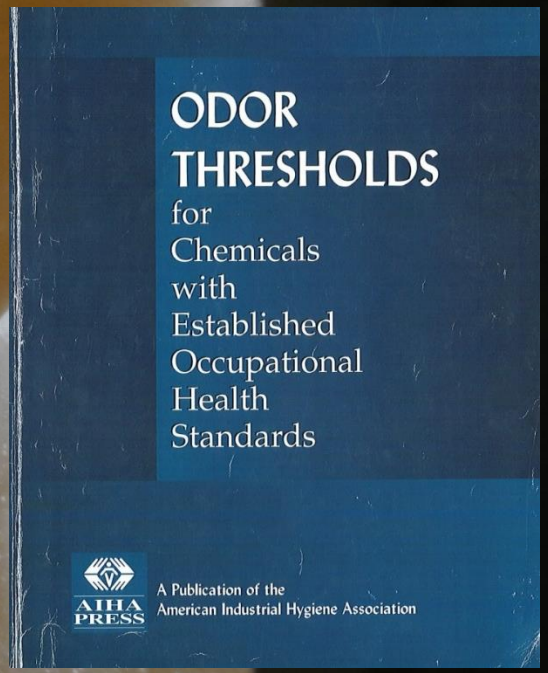


A useful source for understanding **Odor Thresholds**

Odor Thresholds for Chemicals with Established Occupational Health Standards.

American Industrial Hygiene Association, 1995.

ISBN 0-932627-34-X



2%

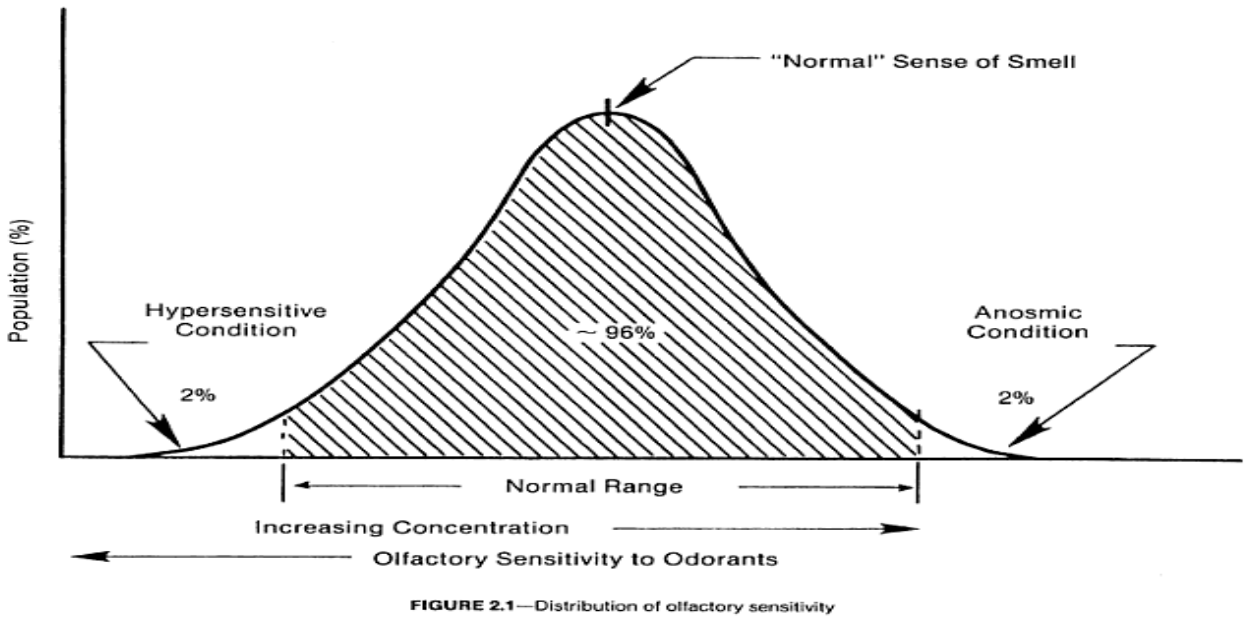


FIGURE 2.1—Distribution of olfactory sensitivity

- Two percent of the population are predictably hypersensitive, and two percent insensitive.
- The insensitive range include people who are anosmic (unable to smell) and hyposmic (partially unable to smell).

Variation

- A person may be **hyposmic** to one odorant and **hyperosmic** to another.
- The variation occurs in specific anosmia and is often caused by repeated exposure to a particular odor. It is not uncommon among chemists or other workers who have had daily exposure to an odorant over a period of years

- The sensitive range includes people who are **hyperosmic** (very sensitive) and people who are sensitized to a particular odor through repeated exposure.
- Individual threshold scored can be distributed around the mean value to several orders of magnitude.

Some odor thresholds

Chemical OEL* (ppm) *Norwegian	Low	High	Geometric mean
Dichormethane (15)	1,2	440	160 d
Styrene (25)	0,017	1,9	0,14 d
Methanol (100)	4,2	5960	160 (all ref.)
Xylene (25)	0,06	40	20d
Hydrochloric acid (5)	0,256	10,1	Not accepted
Formaldehyde (0,5)	0,027	9770	Not accepted
Isopropyl Alcohol	37	610	43
Aceton (125)	3,6	653	62 d
****Ethanol (500)**	**0.09**	**40334**	**Odor properties cannot be used to assess concentration and exposure!**
****Isopropanol (100)**	**1.0**	**2197**	

Odor Thresholds for Chemicals with Established Occupational Health Standards. American Industrial Hygiene Association, 1995. ISBN 0-932627-34-X

** http://cae365.cn/wp-content/uploads/2018/11/Odor-Thresholds-for-Chemicals-with-Established-Occupational-Health-Standards.pdf

Odor fatigue



- After 3 min of exposure to an odorant, the subject's perceived intensity of the odorant is reduced about 75%

Odor Thresholds for Chemicals with Established Occupational Health Standards. American Industrial Hygiene Association, 1995. ISBN 0-932627-34-X

https://en.wikipedia.org/wiki/Olfactory_fatigue

Ultra fine particles and the cardiovascular system

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J Allergy Clin Immunol. Author manuscript; available in PMC 2017 August 01.

Published in final edited form as:
J Allergy Clin Immunol. 2016 August ; 138(2): 386–396. doi:10.1016/j.jaci.2016.02.023.

A Work Group Report on Ultrafine Particles (AAAAI) Why Ambient Ultrafine and Engineered Nanoparticles Should Receive Special Attention for Possible Adverse Health Outcomes in Humans

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[b]Department of Medicine, University of Rochester School of Medicine

[c]Center for Environmental Medicine and Lung Biology, University of North Carolina, Chapel Hill

[d]New York State Department of Health

[e]Division of NanoMedicine, Department of Medicine, University of California Los Angeles

[f]U.S. Army Public Health Command, Toxicology Portfolio, Health Effects Research Program, Aberdeen Proving Ground, MD

[g]UL Environment

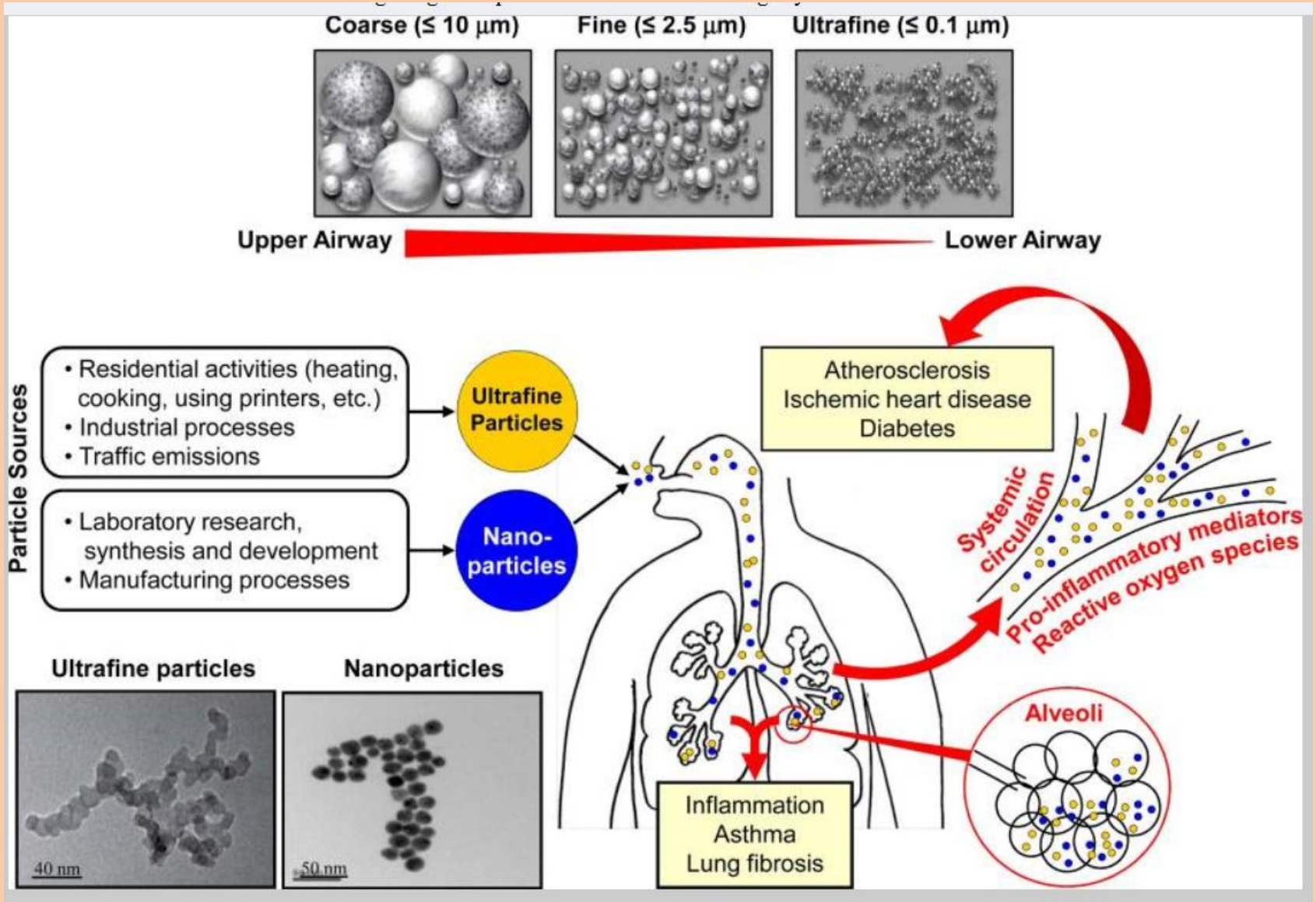
Abstract

Ultrafine particles are airborne particulates of less than 100 nm in aerodynamic diameter. Examples of ultrafine particles are diesel exhaust particles, products of cooking, heating and wood burning in indoor environments, and more recently, products generated through the use of nanotechnology. Studies have shown that ambient ultrafine particles have detrimental effects on both the cardiovascular and respiratory systems, including a higher incidence of atherosclerosis and the exacerbation rate of asthma. Ultrafine particles have been found to alter *in vitro* and *in vivo* responses of the immune system to allergens and may also play a role in allergen sensitization. The inflammatory properties of ultrafine particles may be mediated by a number of different mechanisms, including the ability to produce reactive oxygen species, leading to the generation of pro-inflammatory cytokines and airway inflammation. In addition, because of their small size, ultrafine particles also have unique distribution characteristics in the respiratory tree and circulation and may be able to alter cellular function in ways that circumvent normal signaling

Reprint requests: Andre Nel, MD, 10833 Le Conte Ave, 52-175 CHS, Los Angeles, CA 90095, ANel@mednet.ucla.edu; Ning Li, PhD, 1129 Farm Lane – B43, East Lansing, MI 48840, lining3@msu.edu.

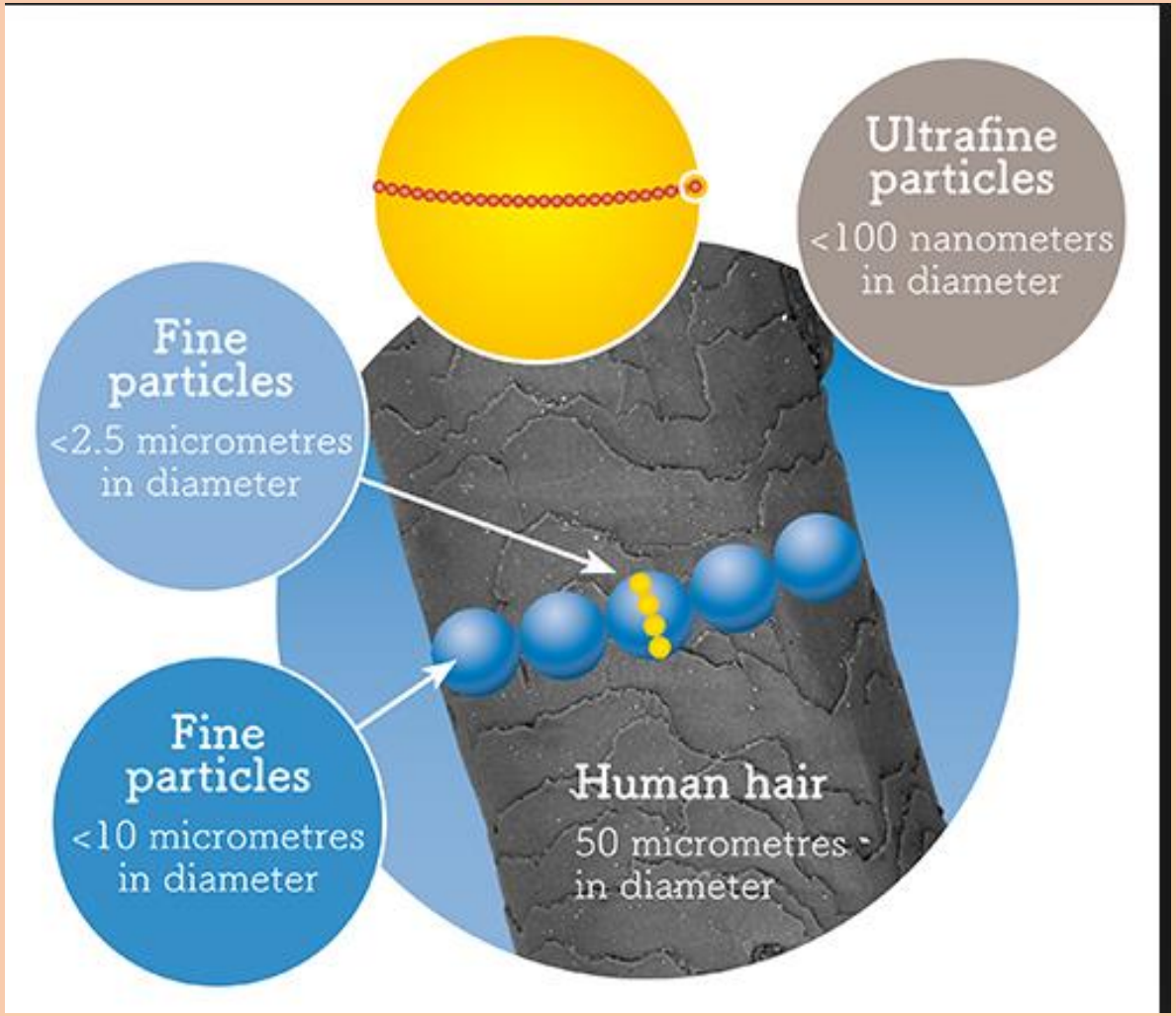
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https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4976002/pdf/nihms774517.pdf

Classification of aerosols



https://interestingengineering.com/dutch-group-creates-outdoor-vacuum-cleaner

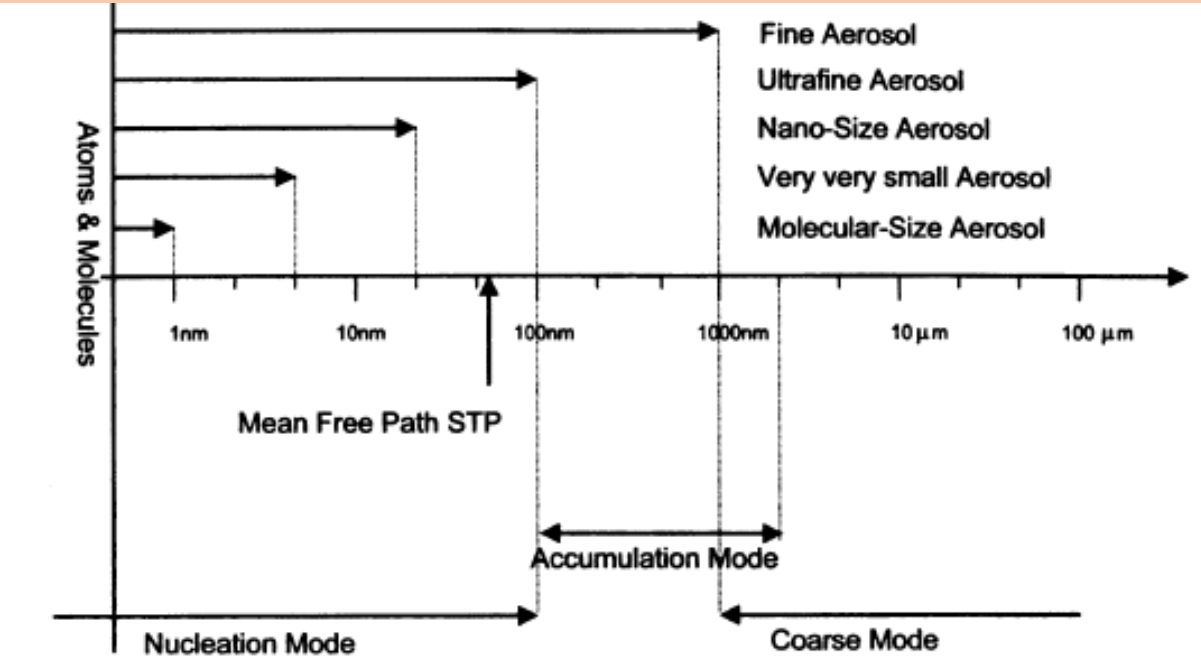


Figure 3.

The particle size classes: **coarse mode**, particles larger than about 1 µm mainly produced by diminution processes; **fine aerosol**, particles smaller than about 1 µm mainly built up by nucleation, condensation and coagulation; **nucleation mode** and **ultrafine aerosol**, particles smaller than about 100 nm; **nanosized aerosol**, particles smaller than about 20 nm; **very very small aerosol**, particles smaller than about 5 nm, particle behaviour dominated by surface effects, total number of molecules less than 500, **molecular size aerosol**, particles smaller than about 1 nm, less than 10 molecules in the particle. Reproduced from Preining (1998).

Particles and ultrafine particles. Surface area and number

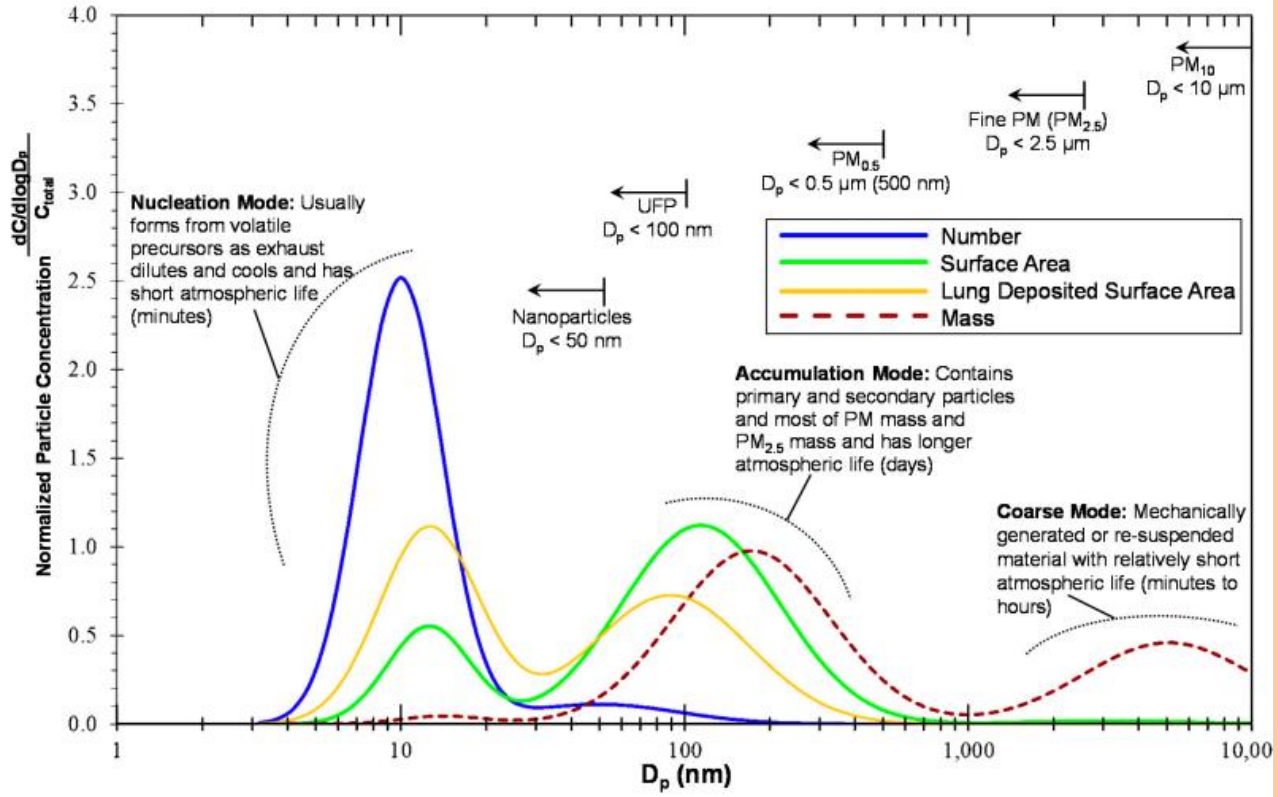
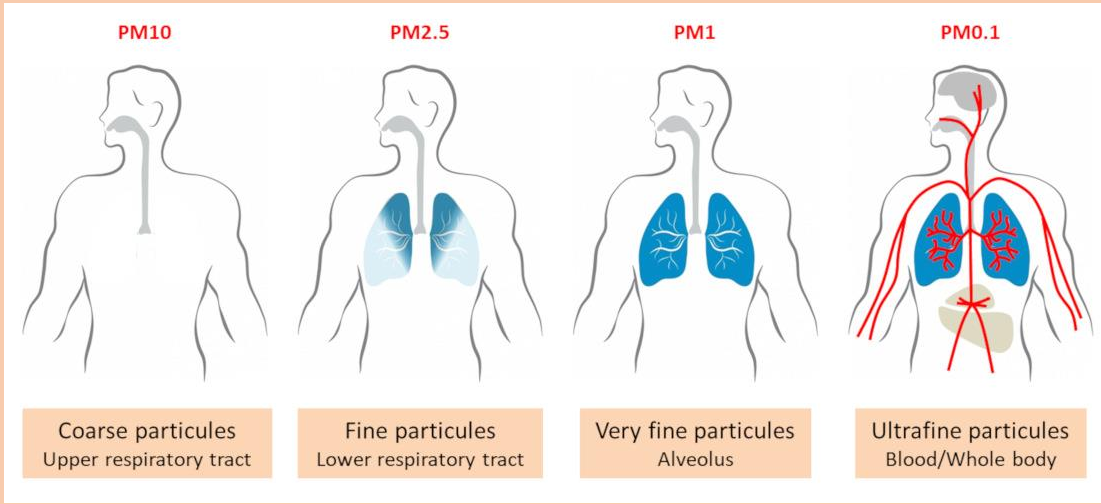


Figure 1. Tri-modal particle size distributions using different particle metrics (number, surface area, lung deposited surface area, and mass). For this figure, D_p is the particle diameter, UFP are ultrafine particles, and PM stands for particulate matter.



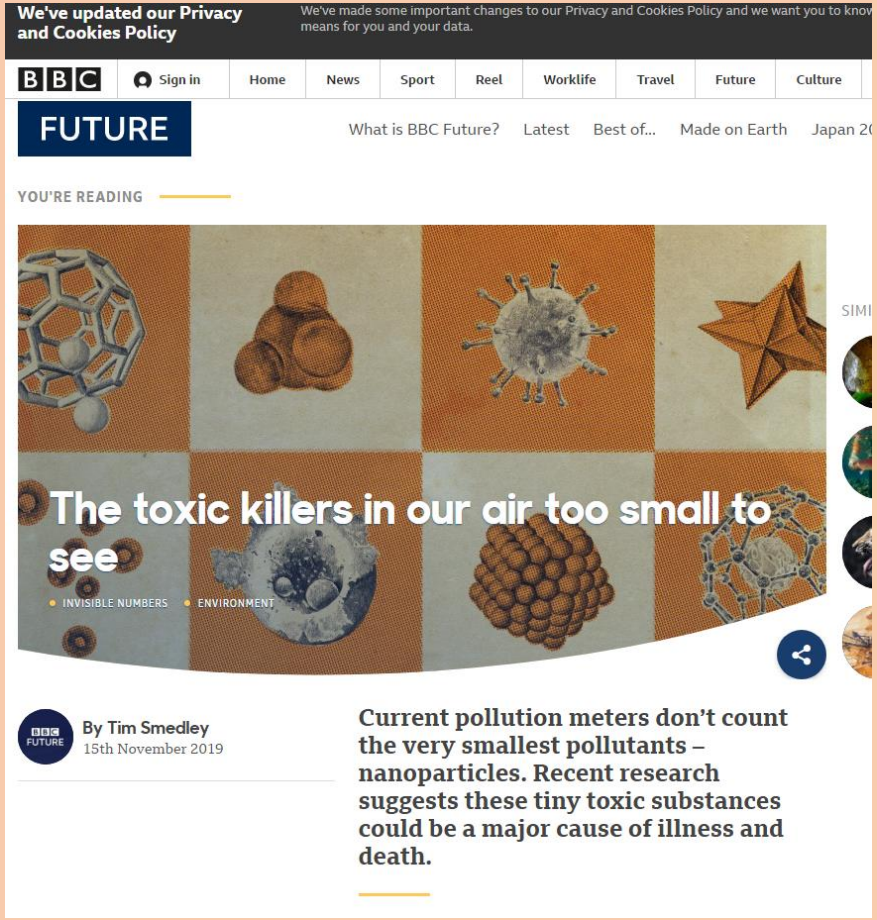
https://www.encyclopedie-environnement.org/en/health/airborne-particulate-health-effects/

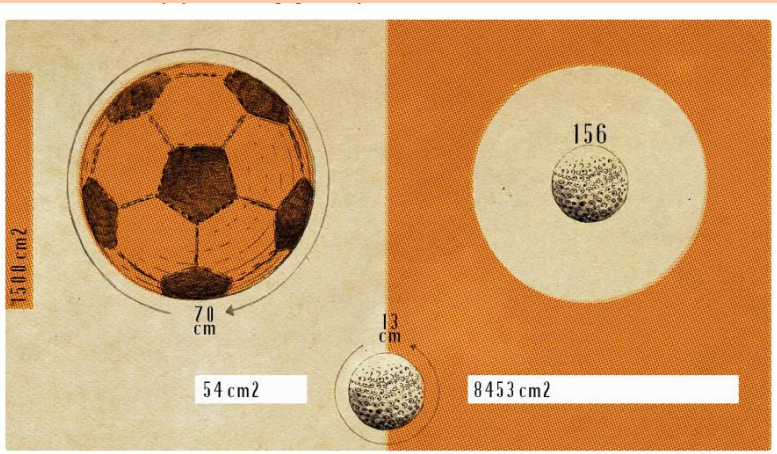
Conference Report

Ultrafine Particle Metrics and Research Considerations: Review of the 2015 UFP Workshop

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5129264/

Particles – size and numbers





The smaller particles actually have a greater collective surface area because there are more of them – and they have a more toxic effect (Credit: Emmanuel Lafont)

A cloud of a billion 10nm particles has the same mass as just one PM10 particle, but a combined surface area a million times larger. And that surface area comes coated with toxic, unburnt fuel from vehicle exhausts.

A cloud of a billion 10nm particles has the same mass as just one PM10 particle, but a combined surface area a million times larger

https://www.bbc.com/future/article/20191113-the-toxic-killers-in-our-air-too-small-to-see

”Houston, we still have a problem”. 2021



January 2006,Chicago. Tristan met his hero, Jim Lovell



Halvor Erikstein
halvor@safe.no
004792810398
www.safe.no

Aircraft Cabin Air International Conference 2021 (ACA 2021) – Proceedings

Conference: Online, 15-18 March 2021
Conference Director: Tristan Loraine
Publisher: London, UK: GCAQE (https://gcaqe.org)
Editors: Dieter Scholz, Susan Michaelis

Considerations and Logistics For Global Ground and in-Flight Trace Contaminant Testing

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Abstract

Purpose: Aircraft ground and flight testing have constraints that must be considered before and during testing to ensure safety of the aircraft operator and test crew.
Methodology: Dr. Richard Fox shares from his 35 years of aircraft cabin air quality planning and testing experiences.
Findings: The industry knew very little about sources of bleed air odors in the first days of testing. Factors such as microbial growth and humidity were first considered as sources for dirty sock odors from aircraft environmental control systems. Little was known during first test encounters as to which equipment would be most appropriate for testing. Much has been learned and test equipment has evolved to current day methods which can speciate chemicals to parts per trillion levels, and portable battery powered equipment such as the Airsense Aerotracer that have been developed through collaboration between aircraft maintenance and sensor manufacturers to provide contaminant source identification.
Research Limitations: Sampling and analytical methods for ground and flight testing have environmental and operational constraints. Aircraft bleed systems produce air at high temperature and pressure which must be conditioned before introduction into real time analyzers or for gathering retrospective samples. Data gathered at altitude (low atmospheric pressure) may require correction for comparison to data gathered at baseline conditions (higher pressure). Sampling location considerations are also of importance. The size and weight of the equipment must be considered. Availability of power if required for equipment must be considered and may constrain types of equipment that can be brought on board. Weight and balance issues also must be addressed for flight test planning. Logistics of transporting and uploading equipment to the aircraft also are not trivial. Test planning begins weeks ahead of a test and includes development of a test plan, shipping lists, aircraft sampling locations, identifying and obtaining special power converters and frequency changers, EMI testing of electronic equipment that will be operated during flights, developing a sampling plan, flight test planning, and flight test airworthiness approval.
Practical Implications: Many changes have occurred over the past 35 years in understanding of testing requirements, equipment capability has evolved, and more targeted testing is now possible.

How to cite this paper: FOX, Richard, 2021. Considerations and Logistics for Global Ground and In-Flight Trace Contaminant Testing. *Aircraft Cabin Air International Conference 2021 (Online, 15-18 March 2021)*. London, UK: GCAQE. Available from: https://doi.org/10.5281/zenodo.4904587
Related presentation: https://doi.org/10.5281/zenodo.4730418
Review process: Editorial review. The corresponding author is marked with *.

Social Implications: This presentation summarizes experiences learned through collaborative efforts of airlines, aircraft Original Equipment Manufacturers, engine manufacturers, regulators, flight crew, cabin crew, and many others whose services are necessary to conduct testing.

Value and Originality: The author is not aware of any open source publication that discusses sampling and testing aircraft cabin environment aspects that are covered in this presentation. Research papers containing data often discuss instrument details, but not what it takes to organize and implement a test strategy.

Keywords

bleed air, contaminant, measurement, flight test, ground test

Considerations and Logistics for Global Ground and In-Flight Trace Contaminant Testing

Dr. Richard Fox

Aircraft Environment Solutions Inc.

March 16, 2021

Aircraft Cabin Air Conference 2021

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Agenda

- Planning & Testing Experience
- Sampling Considerations-Ground & Flight
- Sampling Locations
- Equipment Power
- Staging
- Aircraft Considerations
- Flight Sampling Plan
- Shipping Lists
- Ground Sample Locations
- Ground Testing
- Flight Testing
- Changes Over the Past 30 Years
- Conclusions

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Planning & Testing Experience- 35 Years

- Airbus A320
  - US Airways
- British Aerospace BAE146
  - Dan-Air Services Limited
  - Ansett Australia
  - Sweden-Malmö Aviation
- Boeing B707
  - USAF-JSTARS Conversion from turbo-compressor to bleed air ECS Supply
- Boeing B737
  - Aloha Airlines
- Boeing B757
  - US Airways
  - EASA FACTS Project Test Planning/Preparation
- Boeing B777
  - United Airlines
  - American Airlines
- Dassault Falcon F7X
- Bombardier CRJ
- And Other Commuter and Business Jet Models



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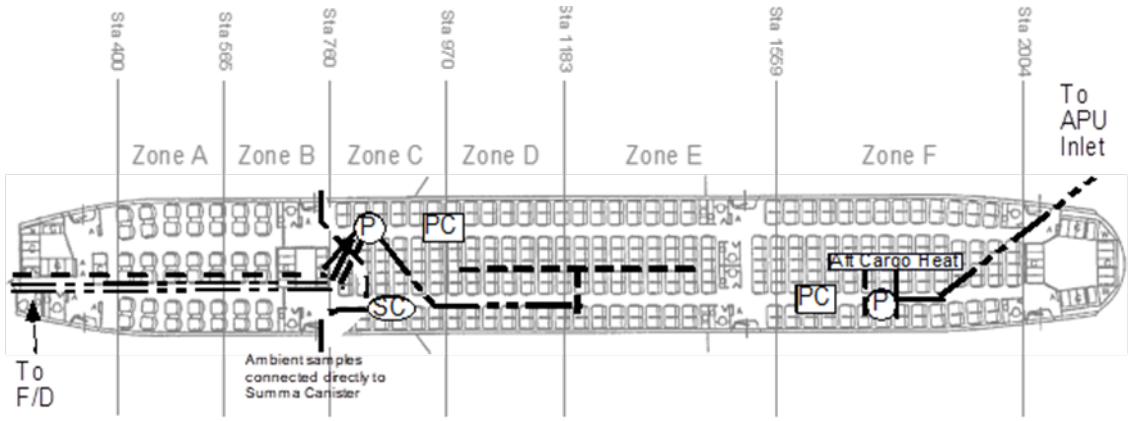
Sampling Considerations-Ground & Flight

- What to Measure (chemical species, contaminant type, potential odor)?
  - Real Time Instrument or Retrospective Analysis?
    - Pressure/Temperature/Flow
    - Ability to carry on-board calibration gas cylinders at the discretion of the airline
  - Retrospective Analysis
    - Adsorbent Media –Sample Volume/Time required to obtain adequate detection limit
      - Pump volume may change with cabin pressure
    - Evacuated canisters- Volume sufficient for detection limit (1 liter vs 6 liter)
    - Tedlar® bags / mylar balloons – Sufficient volume, but only partially fill at altitude (burst risk)
  - Conditioning bleed sample temperature & pressure to atmospheric conditions
  - High and low thermal limitations for instruments
  - Data Logging vs. Handwritten Data for Gas, Particle, Air Speed, etc.
- Type of power required for equipment 120/240VAC, 50/60/400 Hz, single or 3 phase-
  - Acceptable frequency/voltage conversion
  - Acceptable EMI levels
  - 28 VDC aircraft power us
  - usually not available, or is very limited

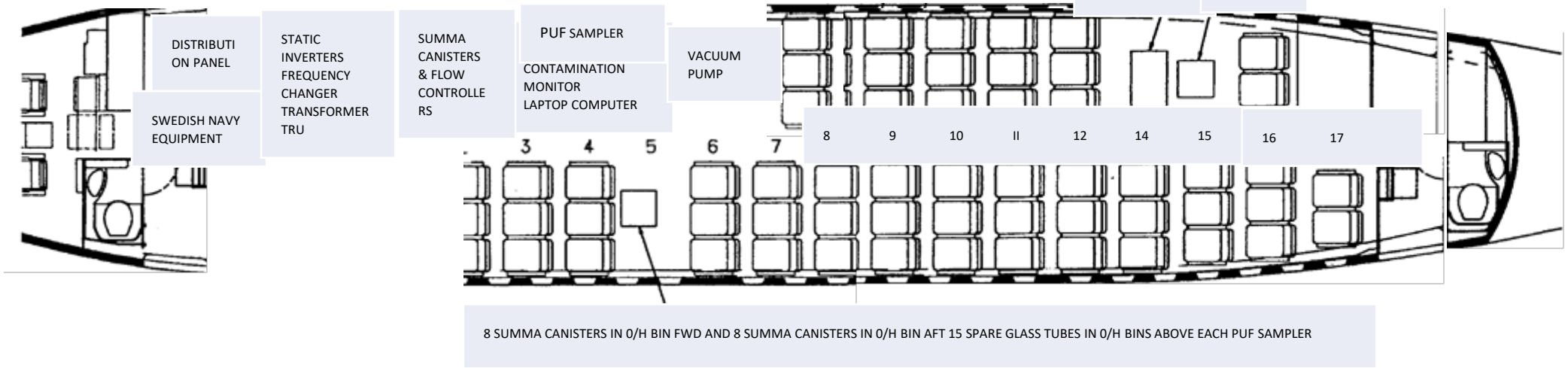
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Sampling Locations

Boeing 777 Sampling Layout:
Cockpit, Manifold in Cabin ,
Bleed from Aft Cargo Heat

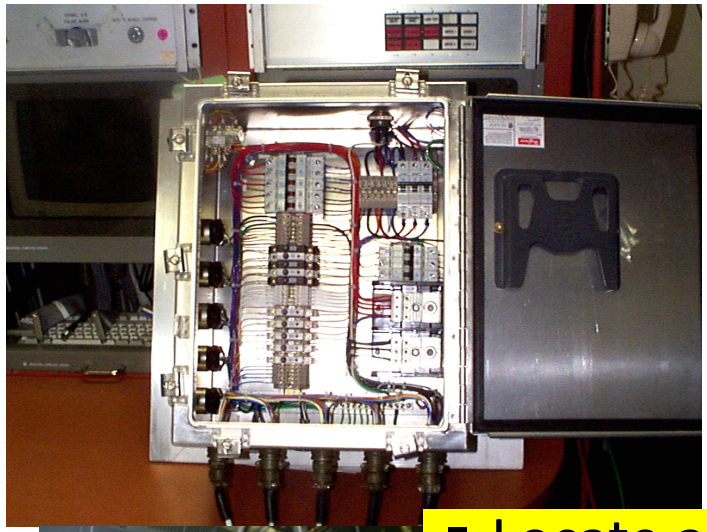


BaE146 Sampling Layout:
Cockpit, Cabin, Aft Galley



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Equipment Power









- Locate adequate power
- Identify conversions required of voltage, frequency, & phase
- Usually 28VDC supply is limited, so must rely on 120 V, 400Hz, 3 Ph. Aircraft power, or Ground Power Source
- Generator in doorway- may create exhaust & Carbon Monoxide in cabin
- Newer electronics may have smaller form factor and lower power requirements



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Staging





Details of Equipment for use on board aircraft for in-flight testing

Aircraft Location

Forward	**Center**	**Rear**
Sample Location		
Install 3" aluminum duct from Louvers above copilots seat, run to forward passenger seating area where puf sample equipment will be secured.		Install 3" aluminum duct from louvers above row 19 seating, run to floor where PUF sampler will be secured.
Secure 3 each 1/8 inch teflon lines to louver and run along side of duct		Secure 3 each 1/8 inch teflon lines to louver and run along side of duct
Line 1- Summa Canister Line 2-DNPH Sampler Line 3- Bleed Air Contamination Monitor		Line 1- Summa Canister Line 2-DNPH Sampler Line 3- Bleed Air Contamination Monitor
Secure sample line for Air Quality Sensor to louver and run along duct		Secure sample line for Air Quality Sensor to louver and run along duct

Bleed Air Contamination Monitor to be Secured in center of passenger seating area. Run Lines 3 from front and rear to area.

DNPH vacuum pump to be centally located by bleed air monitor. Run ¼ inch teflon lines from DNPH sampler boxes to vacuum pump

Summa canisters to be stored in overhead lockers. Spare canisters are stored adjacent to canisters in use and are rotated into the lockers which house flow controllers. 6 summa canisters will be stored in each location.

Considerations for power and power connector, size and weight are as follows:

1.Summa Canisters with mass flow controller
Power:
12 volts dc.
provided by 120 VAC to 12 VDC transformer, 300 mA.
Quantity of 4 ea. (1.2 amps)
power connector- 2 prong flat into power strip- provided by Honeywell

Size:
Box of 2 summa canisters 9 ¼ X 13 ½ x 18 ½ inches, will fit into overhead storage lockers





- Staging prior to equipment upload is necessary to reduce setup time and ensure all equipment is operational after shipment to the test location.
- Do not overlook weight of equipment and how you plan to get it on board

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Aircraft Considerations

Weight and balance changes

	Weight Lb	Arm Ft	Moment lb.ft	Weigh t kg	Arm m	Moment kg.m
Delete:						
Passenger seat - row 1 stbd	-102.7	-20.01	2056.0	-46.6	-6.10	284.3
Passenger seat - row 2 stbd	-93.7	-17.36	1626.1	-42.5	-5.29	224.8
Passenger seat - row 3 stbd	-93.7	-14.70	1377.1	-42.5	-4.48	190.4
Passenger seat - row 4 stbd	-93.7	-12.01	1125.1	-42.5	-3.66	155.6
Passenger seat - row 5 stbd	-93.7	-9.35	876.1	-42.5	-2.85	121.1
Passenger seat - row 5 port	-93.7	-9.35	876.1	-42.5	-2.85	121.1
Passenger seat - row 7 stbd	-93.7	-4.00	375.0	-42.5	-1.22	51.9
Passenger seat - row 8 stbd	-92.6	-1.35	124.6	-42.0	-0.41	17.2
Passenger seat - row 10 stbd	-92.6	3.97	-367.6	-42.0	1.21	-50.8
Passenger seat - row 15 stbd	-67.2	14.67	-986.1	-30.5	4.47	-136.3
Passenger seat - row 16 stbd	-46.3	17.39	-805.0	-21.0	5.30	-111.3
Add:						
Forward attendant	143.0	-24.04	-3437.7	64.9	-7.33	-475.3
Rear attendant	143.0	25.72	3678.0	64.9	7.84	508.5
BAe Engineer x 2 - row 1 port	370.0	-20.41	-7550.4	167.8	-6.22	-1043.9
Honeywell Engineer - row 6 stbd	195.0	-7.05	-1374.8	88.5	-2.15	-190.2
Naval Engineer- row 6 port	185.0	-7.05	-1304.3	83.9	-2.15	-180.4
Bruker Engineer - row 7 port	185.0	-4.40	-814.0	83.9	-1.34	-112.4
Honeywell Engineer - row 9 stbd	150.0	0.92	137.8	68.0	0.28	19.1
Honeywell Engineer - row 9 port	185.0	0.92	169.9	83.9	0.28	23.5
Swedish Naval observers x 2 - row 10 port	370.0	3.61	1335.7	167.8	1.10	184.6
Honeywell Engineer - row 17 stbd	250.0	19.68	4921.2	113.4	6.00	680.4
Bruker Engineer- row 17 port	185.0	19.68	3641.7	83.9	6.00	503.5
Aluminium duct - above co-pilots seat to fwd PUF sampler	3.0	-22.75	-68.3	1.4	-6.93	-9.4
Aluminium duct - above row 16 to aft PUF sampler	2.0	17.00	34.0	0.9	5.18	4.7
Power distribution panel, static inverters, frequency changer, transformer, TRU	240.0	-18.16	-4358.2	108.9	-5.53	-602.5
4 Summa Canisters, 2 mass flow controller	25.0	-12.62	-315.4	11.3	-3.85	-43.6
PUF Sampler	20.0	-10.91	-218.2	9.1	-3.33	-30.2
Vacuum pump	33.0	-4.51	-148.9	15.0	-1.38	-20.6
Bleed air Contamination monitor, laptop computer	60.0	-2.35	-140.8	27.2	-0.72	-19.5
Swedish Navy equipment	135.6	-10.18	-1380.2	61.5	-3.10	-190.8
Gas cylinders in o/h bin above Swedish Navy equipment	122.4	-10.18	-1245.6	55.5	-3.10	-172.2
PUF sampler	20.0	16.42	328.5	9.1	5.01	45.4
4 Summa C controller						
PUF sampl						
8 Summa C						
8 Summa C						
15 spare gl						
15 spare gl						

`Electromagnetic Compatibility' checks

This procedure details the minimum Electromagnetic Compatibility (EMC) tests to be carried out on SE-DRE to demonstrate safety for flight. The test is required as a result of the modifications that have been introduced to configure the aircraft for the purpose of for air quality monitoring.

1. PREPARATION

1.1 Prior to the EMC trial, all relevant aircraft systems must have been declared serviceable.

1.2 All test equipment, including lap top computers to be fully operational and selected ON

1.3 Aircraft to be positioned away from all large structures, all engines running, aircraft on internal power and ground power disconnected.

1.1 All aircraft access panels, hatches and doors closed.

Test Flight Checklists

Resp.	Time	Action	Remarks
C/A		Close door(s) (08:45)	
Pilots		Start APU (08.50)	
Pilots		Select APU bleed ON.	
Pilots		Select both packs ON.	
Pilots		Start main engines (09.00)	
Test team		Switch on all test equipment	–
Pilots/ tech		Start safe for flight EMC check. (09.15)	
		De-ice aircraft if req. (APU bleed OFF)	

LUFTFARTSVERKET
Luftfartsinspektionen

FLIGHT TEST (PERMIT No. 475100 The original of this permit rust be carded on board during all flights. (This time, a TELEFAX-copy will do)

A. PERMIT HOLDER AND AIRCRAFT

Permit holder
Braathens Malmo Aviation, Box 1835, 171 28 SOLNA, Sweden

Registration marking number: SE-DRE

Type designation: 1 Bae 146-200

Serial

B. TEST

Applies to flight test of
Cockpit/Cabin air quality tests with equipment specified in Flight Test Pear, Ref No. L-102/99 and Braathens Malmo Aviation TELEFAX 2000-03-09 from Magnus Bengtsson.

Test program -.
Swedish Board of Accident investigation, Flight Test Plan, Ref No. L -102/99, compiled by BAE SYSTEMS.

Responsible for test
Nils-Gosta Hamnstrom, Flight Safety Officer

Safety Checklists

The procedures listed below are supplementary to the crew emergency checklists that must be accomplished first.

Prior to flight

All test crew must be made familiar with emergency procedures and evacuation drills

Smoke/fumes from test equipment.

Crew	Notify
Equipment	Isolate individual equipment
If smoke continues	
Galley Power switch	SHED

cabin to trou

Weight and Balance, EMI Compatibility, Flight Test Checklists, Safety Checklists, and Flight Test Permits cannot be overlooked

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Flight Sampling Plan

- The flight sampling plan must be coordinated with the flight test plan.
- Consideration must be given for length of time in each phase of flight

Preflight
- All systems off, take measurements (condition .001A)
- APU on while on ground (condition .008)
- Both engines on, APU off (condition .009/.010)
- Taxi (condition .001B)

Flight
- Takeoff & climb (condition .002A)
- Cruise 1st hour (condition .002B)
- Cruise 2nd hour (condition .002C)
- Cruise after 2nd hour for pack and ozone converter isolation (conditions .003, .004, .005 & .006)
  - Flight altitude at 26K (bypass flow control valve closed)
    - Right pack on (isolates right pack & converter) (condition .003)
    - Right pack off, left pack on (isolates left pack and converter) (condition .004)
  - Flight altitude 20K (bypass flow control valve opens)
    - Left pack off, right pack on, trim PRSOV off (isolates right pack) (condition .006)
    - Right pack off, left pack on, trim PRSOV off (isolates left pack) (condition .005)

Postflight
- Swab samples and visual inspection (condition .007). Locations:
  - APU inlet - at aircraft skin
  - APU inlet - at inlet screen
  - APUSOV
  - Left pack flow control valve
  - Left pack flow control valve-bypass
  - Right pack flow control valve
  - Right pack flow control valve-bypass
  - Precooler inlet pan/core face
  - Downstream of primary and secondary pack heat exchangers
  - Upstream of ozone converter inlet
  - Air driven pump
  - Hydraulic leakage

<u>Test Measurement Equipment</u>

Hand held:
- Metrosonics AQ 501: measures C02, C0, RH, Temp. & Pres.
- TSI Qtrak: measures C02, CO, RH and temperature
- Lumidor Micro Max: measures CO, 02 and H2S
- Sensidyne Tubes: measures CO, O3 and Formaldehyde

Other:
- Summa canisters: measures CO, C02, VOCs, other gases
- DNPH cartridges & Tedlar bags: measures Aldehydes

1. PUF plugs: measure particulates

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Shipping Lists

Equipment inventory shipped to Malmo Sweden 2/24/00

	Estimated Value for Customs
BOX 1 (large gray plastic)	
1 tool box with assorted hand tools	
2 - DNPH sampling boxes	
Assorted fittings, teflon tape	
Paper towels, aluminum foil, tape, batteries	
Tie wraps, Labels, 2 - stop watches	
Quartz fiber filters	
4 -plastic caps	
3 - plastic tubing flanges w/ hose clamps	
1 - staplex calibration orifices	
2 - support brackets, digital pressure gauge	
	$500.00
BOX 2 (large gray plastic)	
Heise digital manometer	
Hanna digital hygrometer	
4 - extension chords	
1 - KNF vacuum pump	
3 - power strips	
4 - AC converters	
1/4" teflon tubing ~200'	
1/8 teflon tubing ~200'	
6 - tedlar bags	
1 - Teledyne pressure transducer	
	$500.00
BOX 3 (small black plastic)	
1 - spare tisch vacuum motor	
1 - spare tisch magnahelic	
1 - spare elapse time indicator	
	$500.00
BOX 4 (small black plastic)	
8 - PUFF sampler flanges	
	$100.00
BOX 5 (aluminum)	
8 - PUFF sample housings	
	$100.00
BOX 6 (aluminum)	
1 - Tisch vacuum motor	
1 - Tisch magnahelic	
1 - Tisch elapse time indicator	
1 - stop watch	
various fittings	
	$500.00
BOX 7 (aluminum)	
1 - Tisch vacuum motor	
1 - Tisch magnahelic	
1 - Tisch elapse time indicator	
1 - stop watch	
various fittings	
	$500.00
BOX 8 (medium card board)	
2 - 3"aluminum duct	
	$10.00
Ice Chest #1 (large blue plastic)	
12 - PUFF cartridges	
2 - Sensidyne hand pumps	
50 - DNPH cartridges	
4 - Packs of Sensidyne tubes	
	$200.00
Ice Chest #2 (large red plastic)	
10 - PUFF cartridges	
	$100.00
Ice Chest #3 (small white plastic)	
4 - PUFF cartridges	
	$40
BOX 9 (medium card board)	
4 - Summa canisters	
	$400.00
BOX 10 (medium card board)	
4 - Summa canisters	
	$400.00
BOX 11 (medium card board)	
4 - Summa canisters	
	$400.00
BOX 12 (medium card board)	
4 - Summa canisters	
	$400.00
BOX 13 (medium card board)	
4 - Summa canisters	
	$400.00
BOX 14 (medium card board)	
4 - Summa canisters	
	$400
BOX 15 (medium card board)	
2- battery packs w/ AC adaptors	
garbage bags	
large ziplock bags	
2- clipboards	
pens/markers	
packing tape	
	$50.00
BOX 'A' (large card board)	
2 - aluminum mounting plates for inverters	
3 - static inverters	
BOX 'B' (large card board)	
2 - aluminum mounting plates for inverters	
3 - static inverters	
5 - inverter cables	
2 - B.A.M. catalysts (spares)	
Calgaz regulators	
Dynamation regulator	
alde' badges, etc.	
BOX 'C' (small card board)	
Dynamation gas detector	
1 - battery pack	
BOX 'D' (large card board)	
Bleed Air Monitor	
BOX 'E' (large card board)	
transformer	
catalyst	
BOX 'F' (large card board)	
B.A.M. sample lines	
catalyst	
Alicat flow controllers	
Drager pump	
misc. elec. cords	
packing tape	
travelers for Performance Analytical	
Total US Dollars	10,000

Shipping lists with values for customs and country of equipment origin are essential to ensure timely Customs Clearance

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Ground Sample Locations

- Low Pressure PCA Port- Recirculated Air
- High Pressure Start Port- Bleed
- Cabin Supply- Mix of Bleed and Recirculated
- Cockpit Supply-Fresh Air
- Reference Air Sample- high outside to avoid exhaust recirculation



Ground Sampling Considerations:

- Engine noise, exhaust ingestion from engines and ground power units, conditioning bleed air temperature and pressure
- Test adaptors modified to work for all aircraft HP and LP bleed ports
- Ambient sample above emergency egress door had less exhaust ingestion than sample tube on engine pylon

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Ground Testing





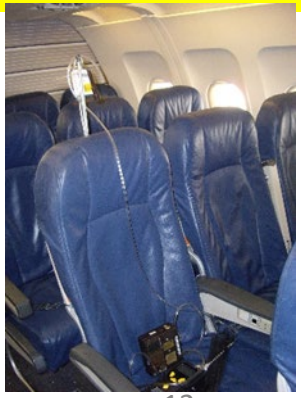












Ground Test Considerations:

- Maximum Thrust achievable on ground test to operate LP & HP Bleed Ports
- Use Static Frequency Changer to adapt between 50, 60, and 400 Hz
- Ambient sample above emergency egress door had less exhaust ingestion than sample tube on engine pylon
- Barriers and hearing protection required when stationed outside the aircraft.
- Limitations on pressure and temperature conditioning of bleed air

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Flight Testing

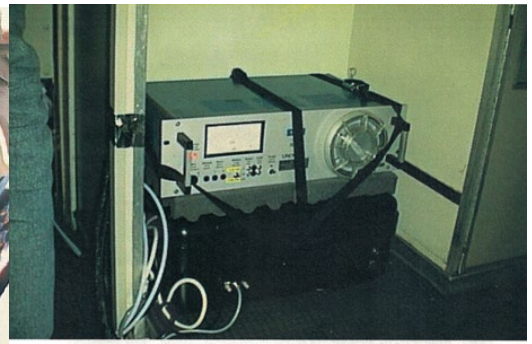
Flight Sampling – equipment and lines must be secured

- Cockpit -must not obstruct pilots
- Cabin – no loose equipment
- Bleed Duct- lines must be routed to sampling location from bleed source
- Retrospective samples may require cold storage

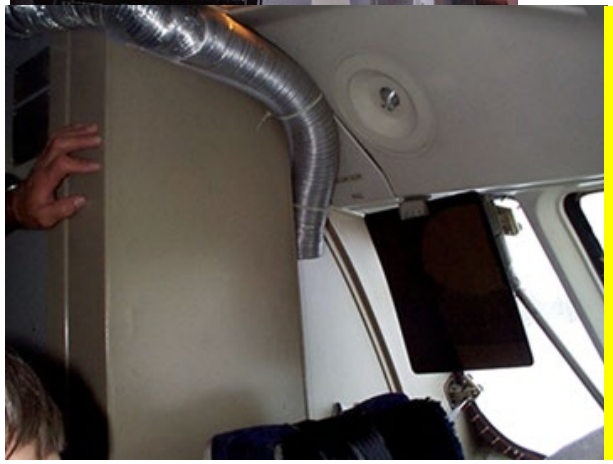




Sampling point for the Air Quality Monitor, 5 cm above the air inlet that is located on the starboard wall panel of the cockpit.



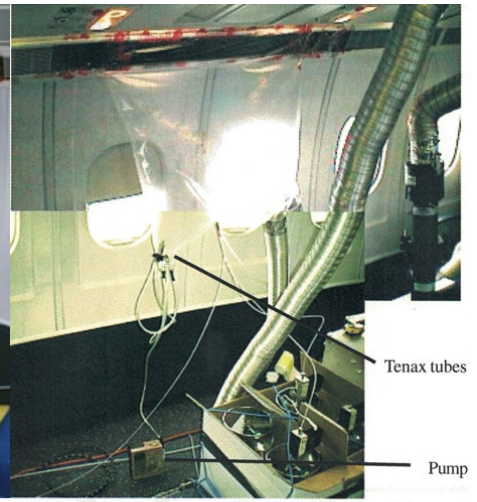
Air Quality Monitor (at the bottom) with the Infra Red carbon monoxide detector on the top. The equipment was placed in the fore part of the cabin,



Retrospective analysis:

- 60 pptV detection limits for SVOC
- VOC detection limits below odor thresholds





Sampling point for retrospective analysis of volatile organic compounds. To the right equipment used by Honeywell can be seen. A plastic bag was mounted over the louvers to make sure that gas was not sampled directly from the cabin.







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Changes over the Past 30 Years

1991-UK

DAN AIR
Minimal Instruments
Balloon Sample-TVOC
Dirty Socks Odor

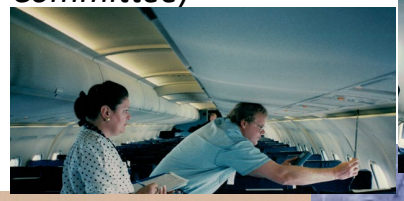
(Microbial Analytical Support by Pall Aircraft Maintenance *Porous Media Europe LTD; Rolls-Royce Derby)*

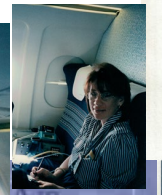


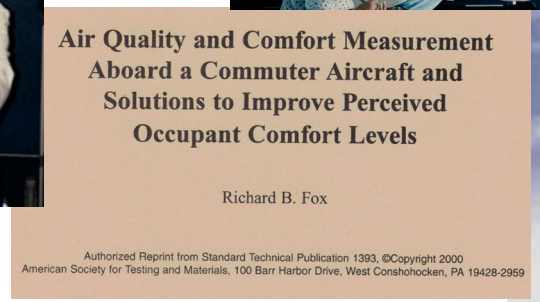
1997-Australia

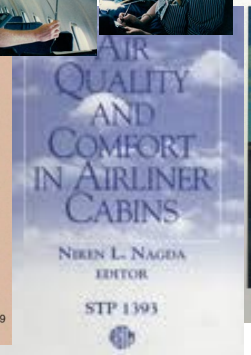
ANSETTE AIRLINES
Ground & Flight
Filter Analysis
Pack Burn Analysis
SUMMA Canister-VOC
Low Volume PUF

(Support by Queensland Health Scientific Services;. Hand Data Collection by Flight Attendant Union Safety Committee)





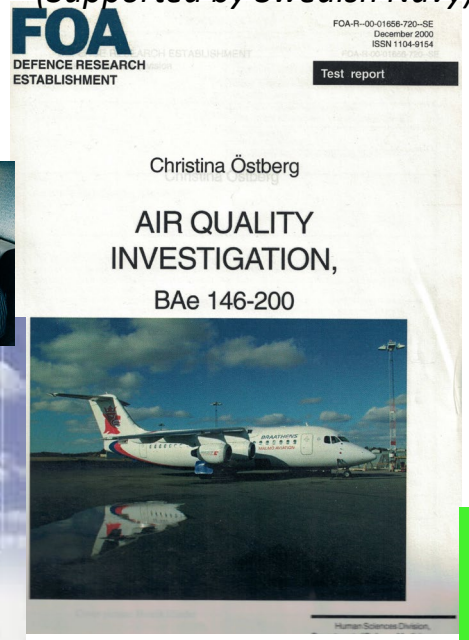




2000-Sweden

MALMO AIRLINES
Data Acquisition Systems
High Volume PUF-SVOC
DNPH-Aldehydes
TENAX-VOC
Instruments-CO, O3, TVOC

(Supported by Swedish Navy)



2021

ASHRAE/FAA-UFP & Bleed Air Sensor Research

Goal: Source Sampling for maintenance Troubleshooting

Led by Kansas State U Oversight-ASHRAE/FAA
(Supported by *Numerous Industry Participants)*



Progression from trying to identify chemistry of observed odors to Source Identification for Predictive and Preventative Maintenance

Assessing Aircraft Supply Air to Recommend Compounds for Timely Warning of Contamination by Fox, Richard B., Ph.D., Northcentral University, 2012, Open Access

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Conclusions

- Need to know the aircraft ECS system you are testing, and the ECS Control logic for that system
- Need to know electrical systems of the aircraft to understand power availability
- Need to be mindful of ambient and recirculated exhaust contamination during ground testing
- Desired levels of detection of chemical species or substance to be identified will dictate type of sampling equipment
- Instrument correction for temperature and pressure is essential during ground and flight tests
- Need to know instrument environmental limits- may need to shelter and thermally condition instruments if testing in an extreme cold or extremely warm environments
- Total equipment weight is a consideration.
- Over the past 30 years the instrument form factors have become smaller and lighter, power consumption has diminished, detection limits and compound identification have improved
- Aircraft specific cabin air sensors are coming on the market in the near future that will enable airlines and OEMs to obtain real time data on aircraft cabin environment conditions

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Have You Been Exposed to Aircraft Engine Oil? - Biomarkers of Exposure

Clement Furlong

Professor of Medicine and Genome Sciences - University of Washington

Co-Authors UW: Prof. Allan Rettie, Dr. Alex Zelter, Dr. Matthew McDonald, Prof. Michael MacCoss, Asst. Prof. Judit Marsillach, Tom Bukowski, Rebecca Richter; Oksana Lockridge (U Nebraska)

Aircraft Cabin Air Conference 2021

Research Team



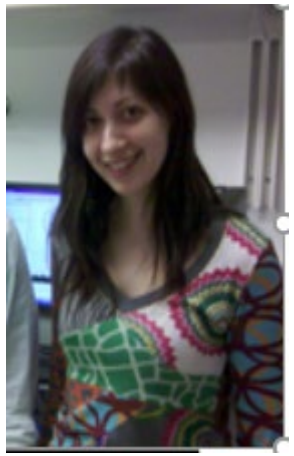
Prof. Allan Rettie



Dr. Matt McDonald



Dr. Alex Zelter



Asst. Prof. Judit Marsillach



Prof. Oksana Lockridge



Professor Mike MacCoss



Professor Clem Furlong



Sr. Scientist Tom Bukowski



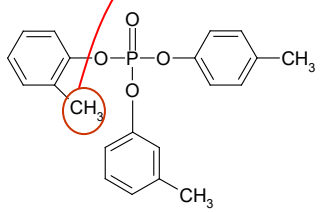
Sr. Scientist Becky Richter

Fume Event

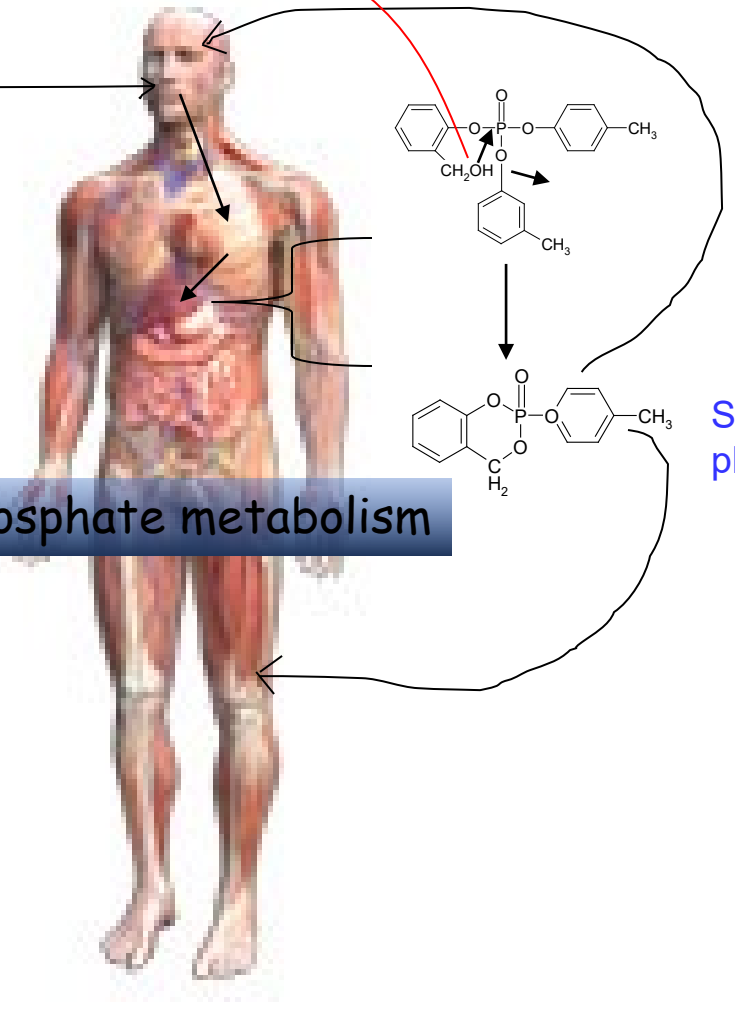


The Problem

Oxidized by cytochromes P450

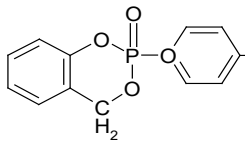


Monoorthocresyl phosphate



Triaryl phosphate metabolism

Saligenin cyclic cresyl phosphate (CBCP)



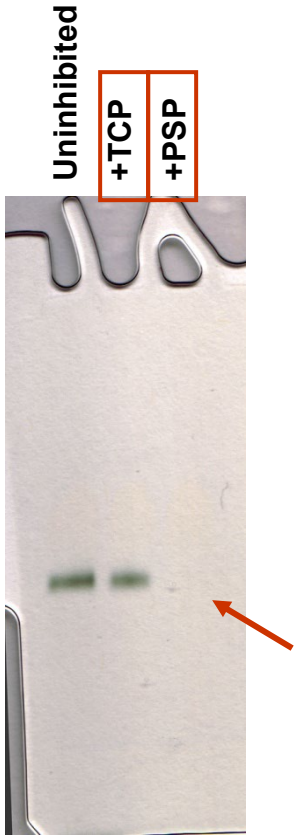
PSP



Dr. Matt McDonald

Matt showed this P450 to be CYP3A4

Searching for Useful Biomarkers in Human Blood Samples



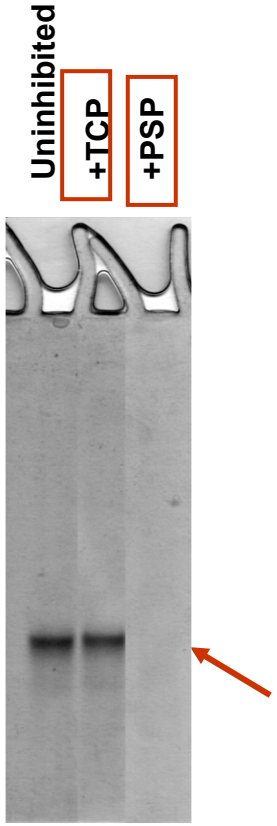
Plasma Butyryl Cholinesterase

~11 d ½ life



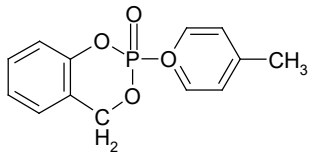
Red cell Acetyl Cholinesterase

~33 d ½ life

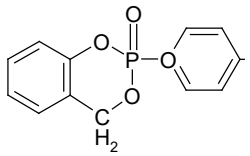


Monocyte Carboxylesterase

½ life unknown



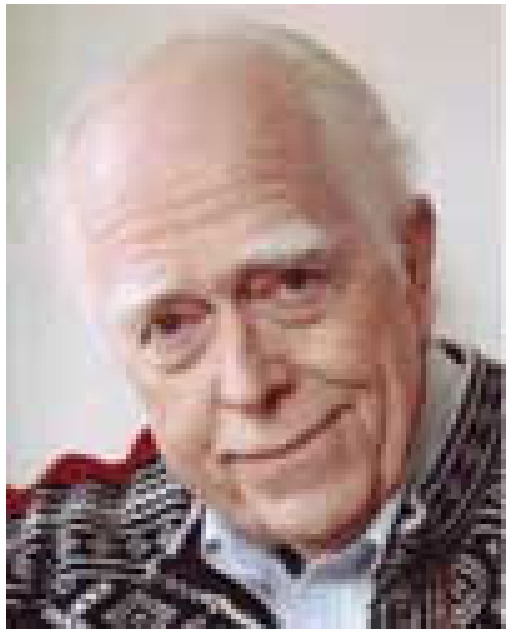
CBDP



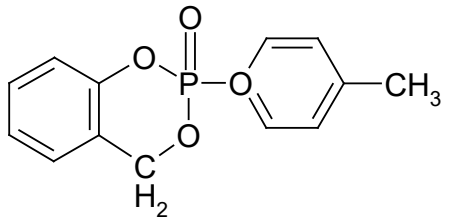
PSP

PSP and CBDP are a very potent inhibitors of esterases

Professor John Casida, UC Berkeley



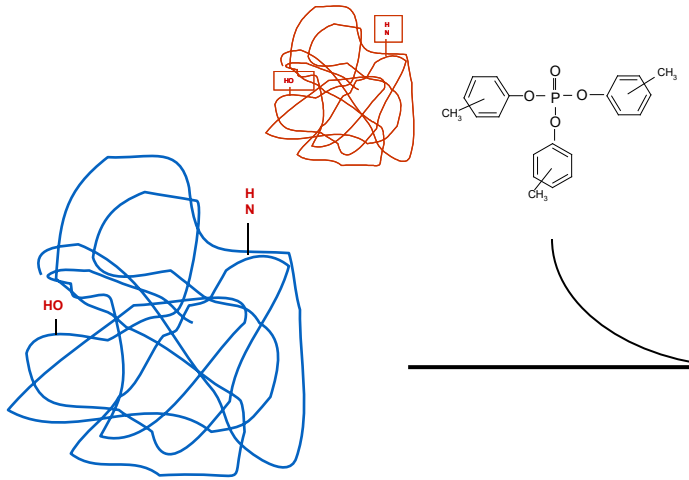
1929-2018



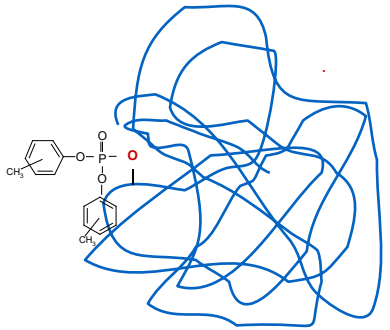
Professor Casida identified CBDP as the active metabolite formed from bioactivation of T*o*CP

Casida, J.E., Eto, M. and Baron, R.L. Biological activity of a tri-*o*-cresyl phosphate metabolite. Nature (Lond.) 191 (1961) 1396–1397.

Modified Protein Biomarkers of Exposure

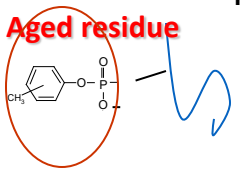


Protein



Modified Protein

Digest with specific proteases

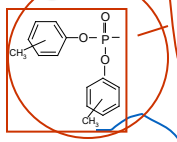


Aged residue

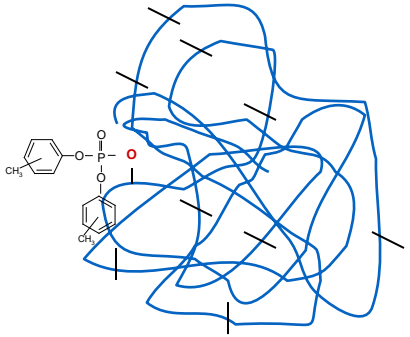
This also holds for insecticide exposures

O=P-OEt (unaged)
|
OEt

O=P-OEt (aged)
|
O⁻



Un-Aged residue



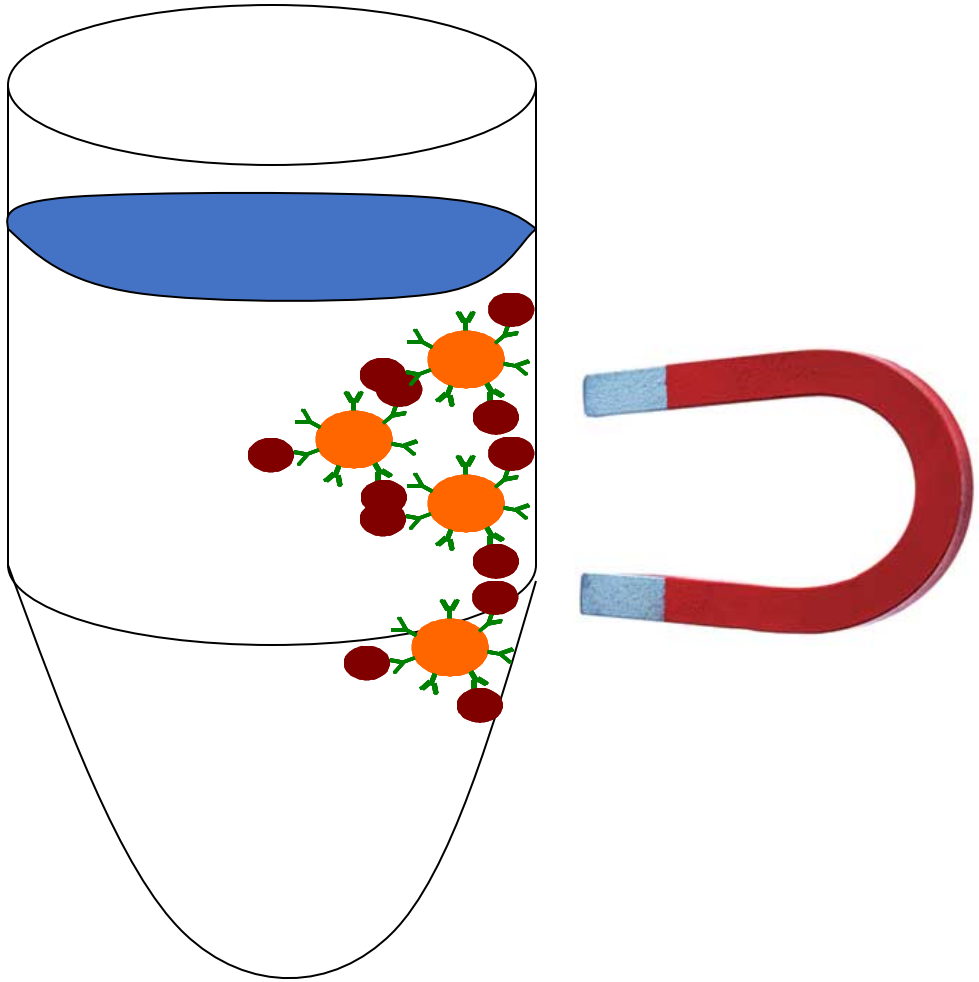
Separate Fragments

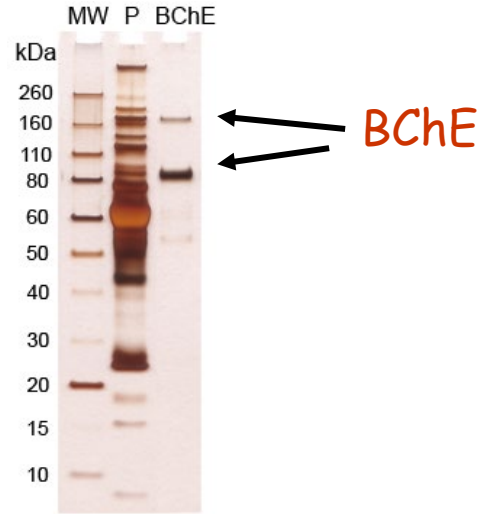
To mass spectrometer

Ion funnel equipped LTQ (MacCoss lab.) Increases Sensitivity 6-10X



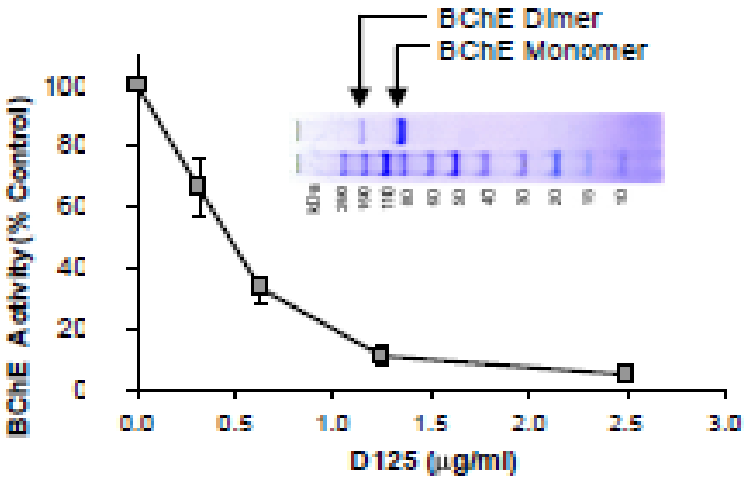
Immuno Magnetic Bead Separation (IMS)

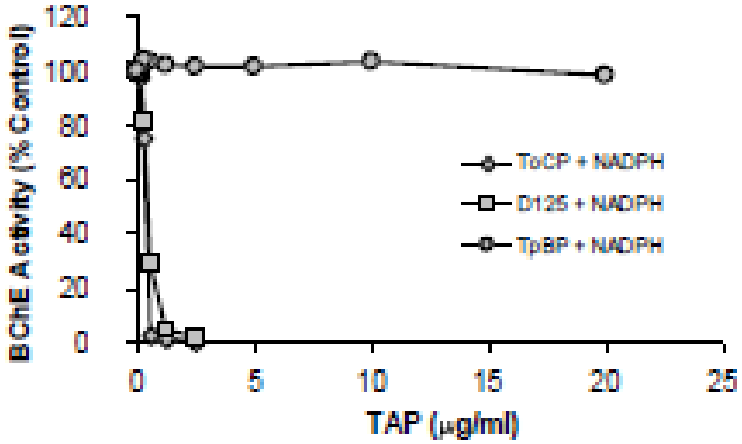




BChE Inhibition with the *in vitro* Assay

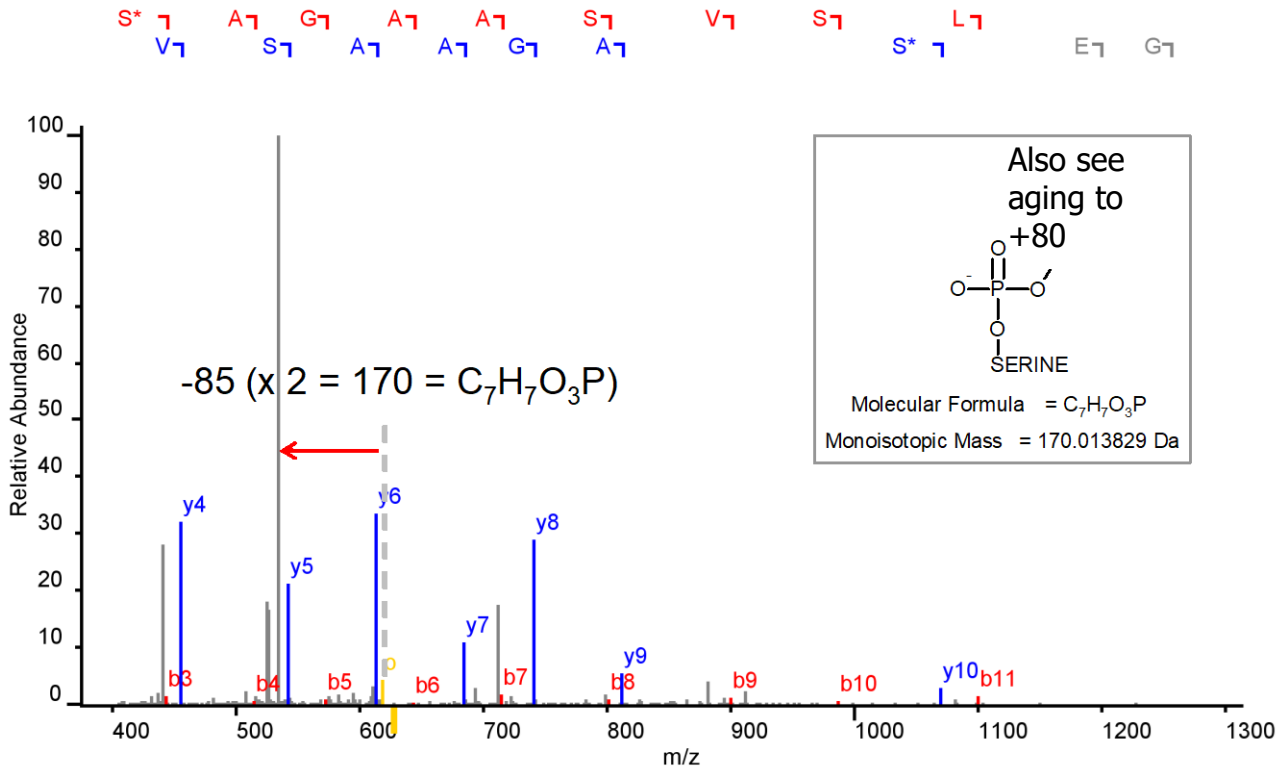
(Incubate TAP with P450s ±NADPH; add BChE, measure activity)





Mass Spec Analysis of OP Modified Protein

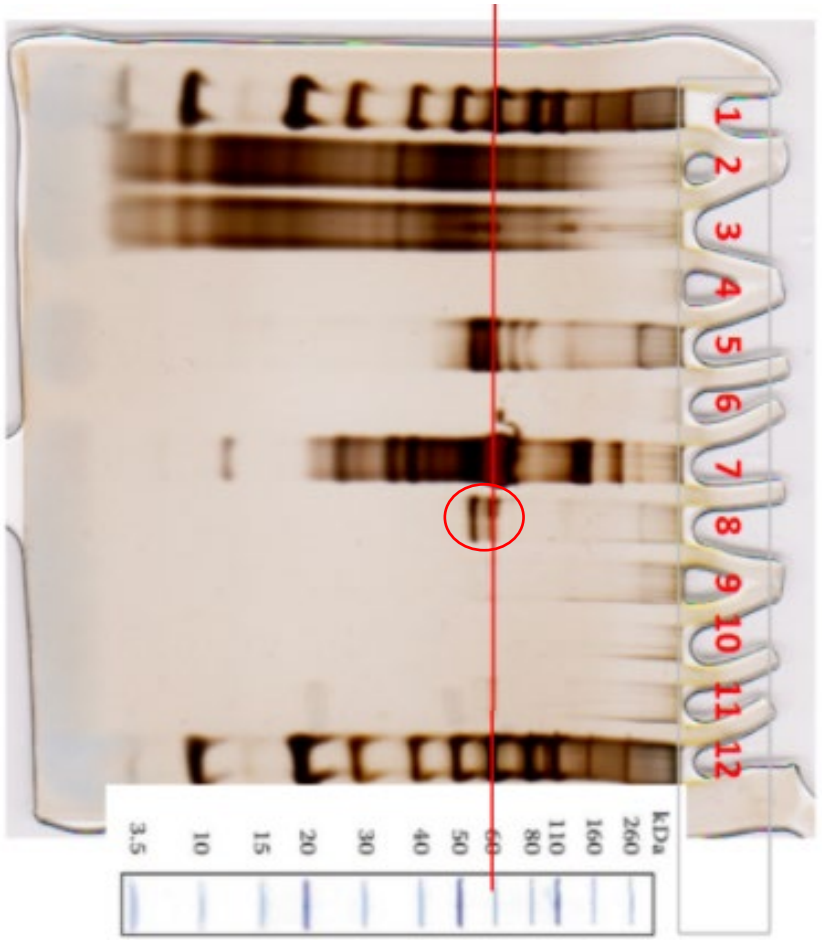
Chymotrypsin digestion
F.GES*AGAASVSLH.L
*: CBDP / +170



Mike MacCoss & Daniela Tomazela

Schopfer et al. Anal Biochem 2010

Purification of RBC ChE



Lane 1 Molecular Weight markers

Lane 2 Sample from DEAE to Mag beads

Lane 3 Sample after Mag beads

Lane 4 Empty

Lane 5 BASE eluted AChE before Zeba desalting

Lane 6 Empty

Lane 7 BSA

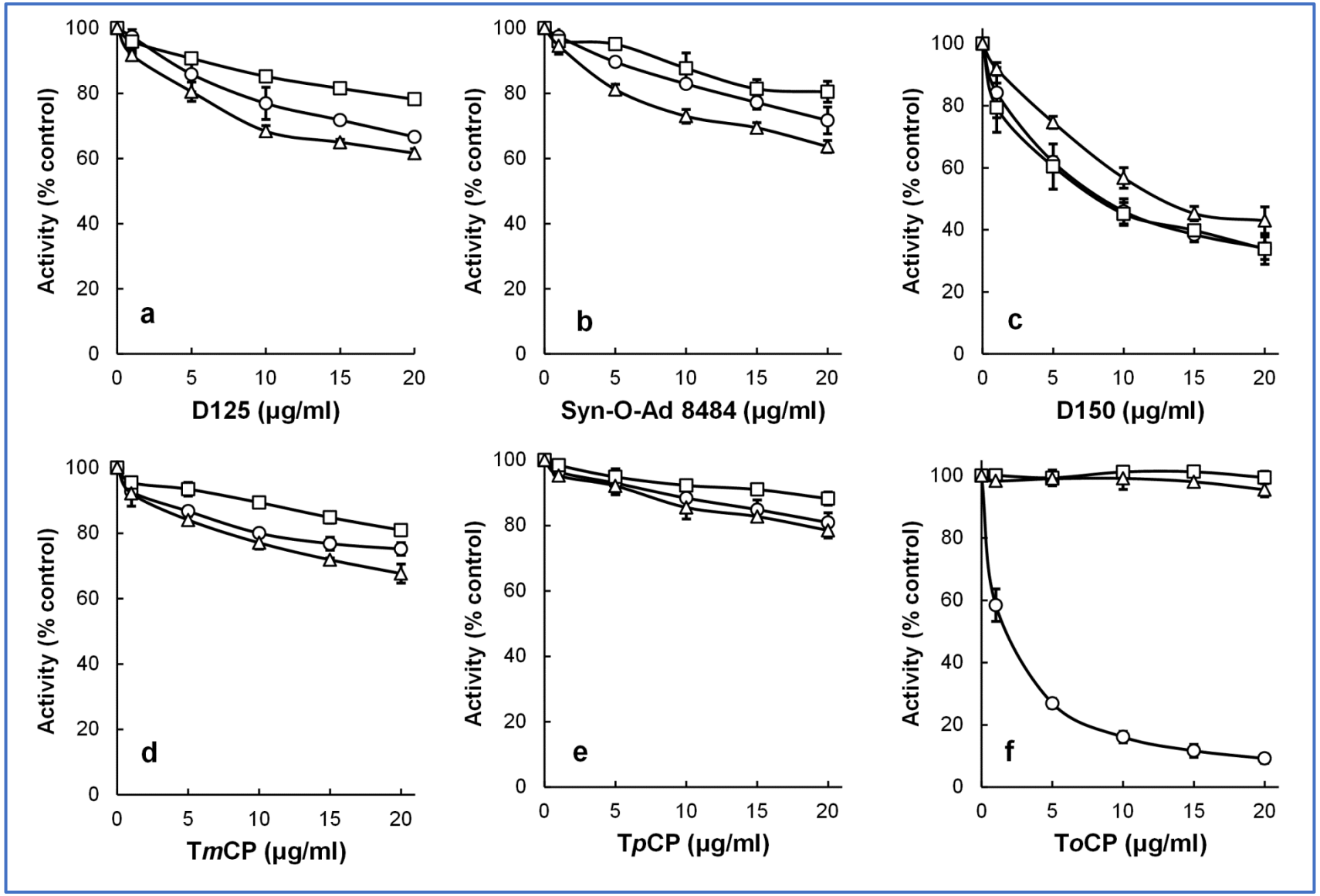
Lane 8 BASE eluted AChE AFTER Zeba desalting

The next series of slides shows the concentration dependence of inhibition of several potential biomarker proteins by different triaryl phosphates (commercial mixtures and pure compounds) in the presence and absence of bioactivation by cytochromes P450.

Acetylcholinesterase

Legend

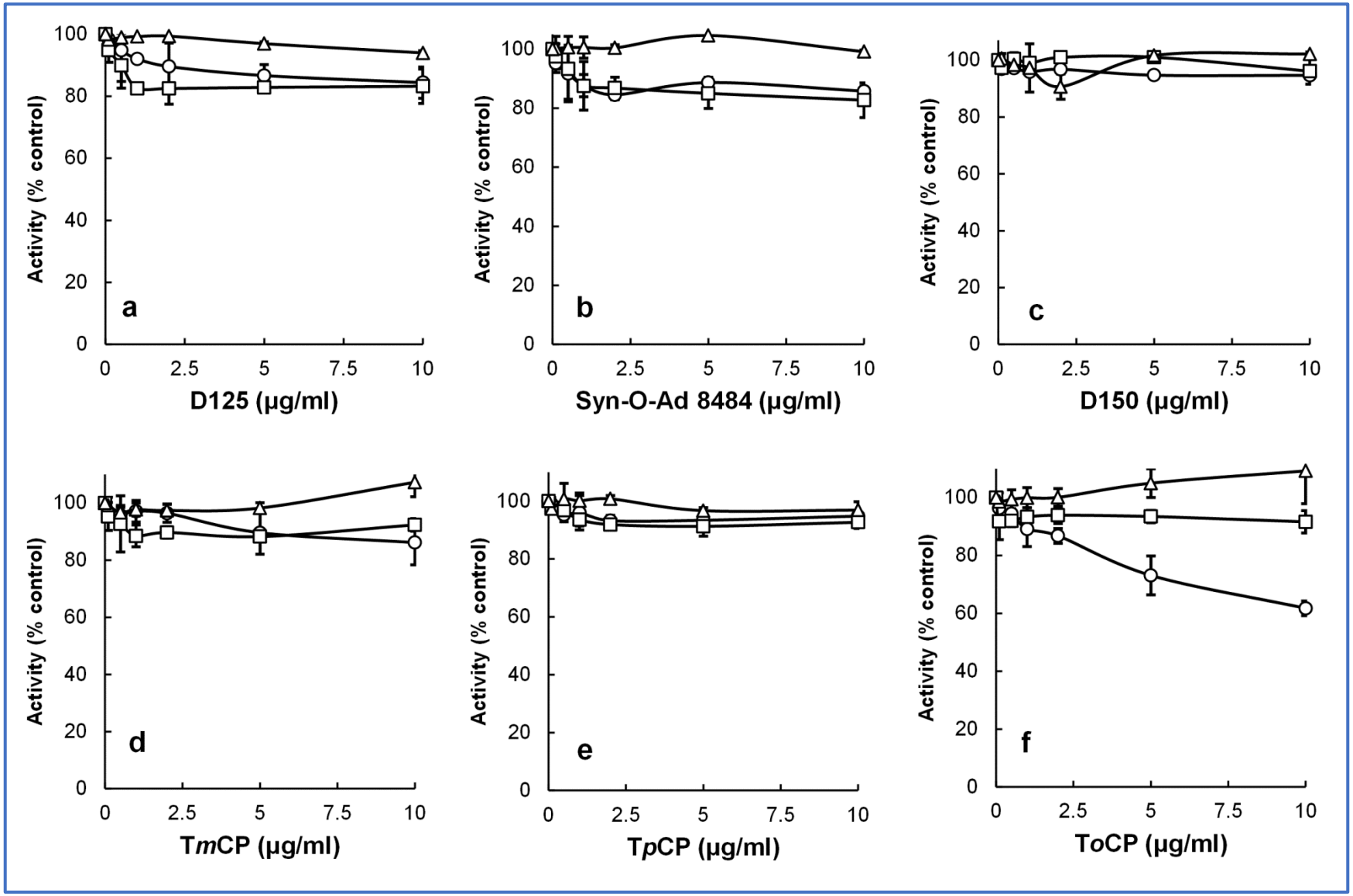
○ Complete assay □ Complete assay minus NADPH △ TAP only



Acylpeptide Hydrolase

Legend

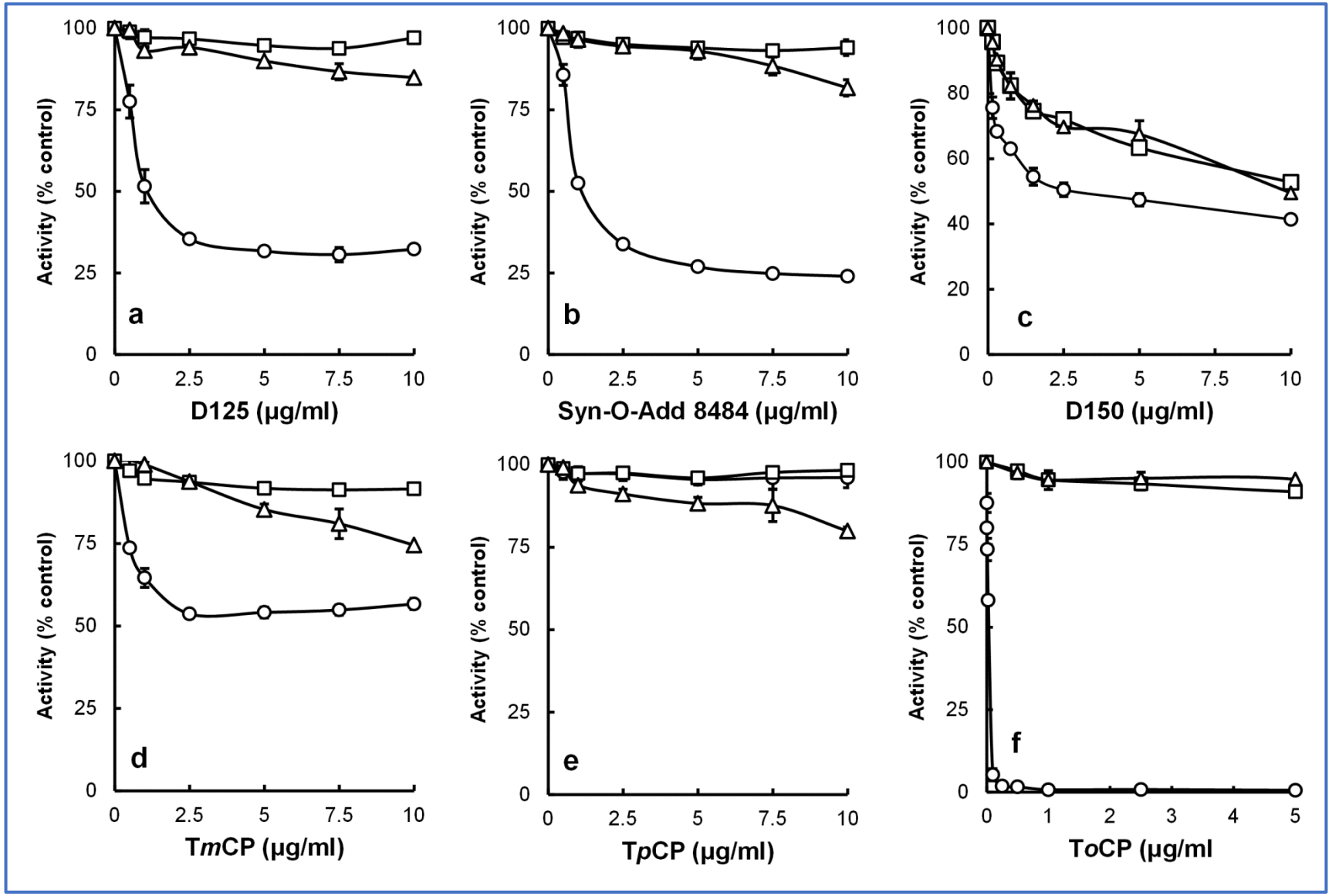
○ Complete assay □ Complete assay minus NADPH △ TAP only



Butyrylcholinesterase

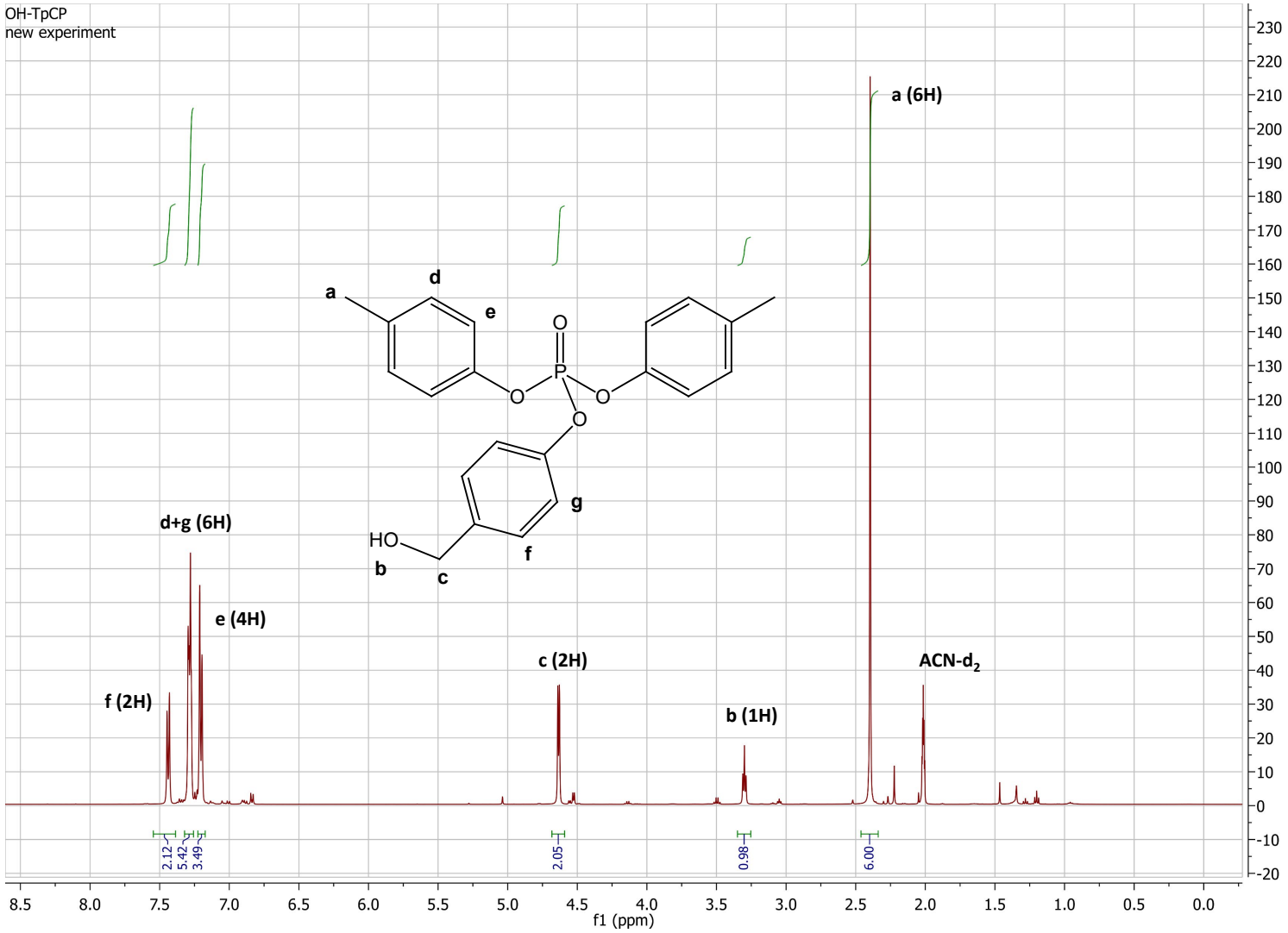
Legend

○ Complete assay □ Complete assay minus NADPH △ TAP only



Metabolism of T*p*CP by Cytochrome P450 2B6

^{1}H-NMR Spectrum of OH-Me-T*p*CP

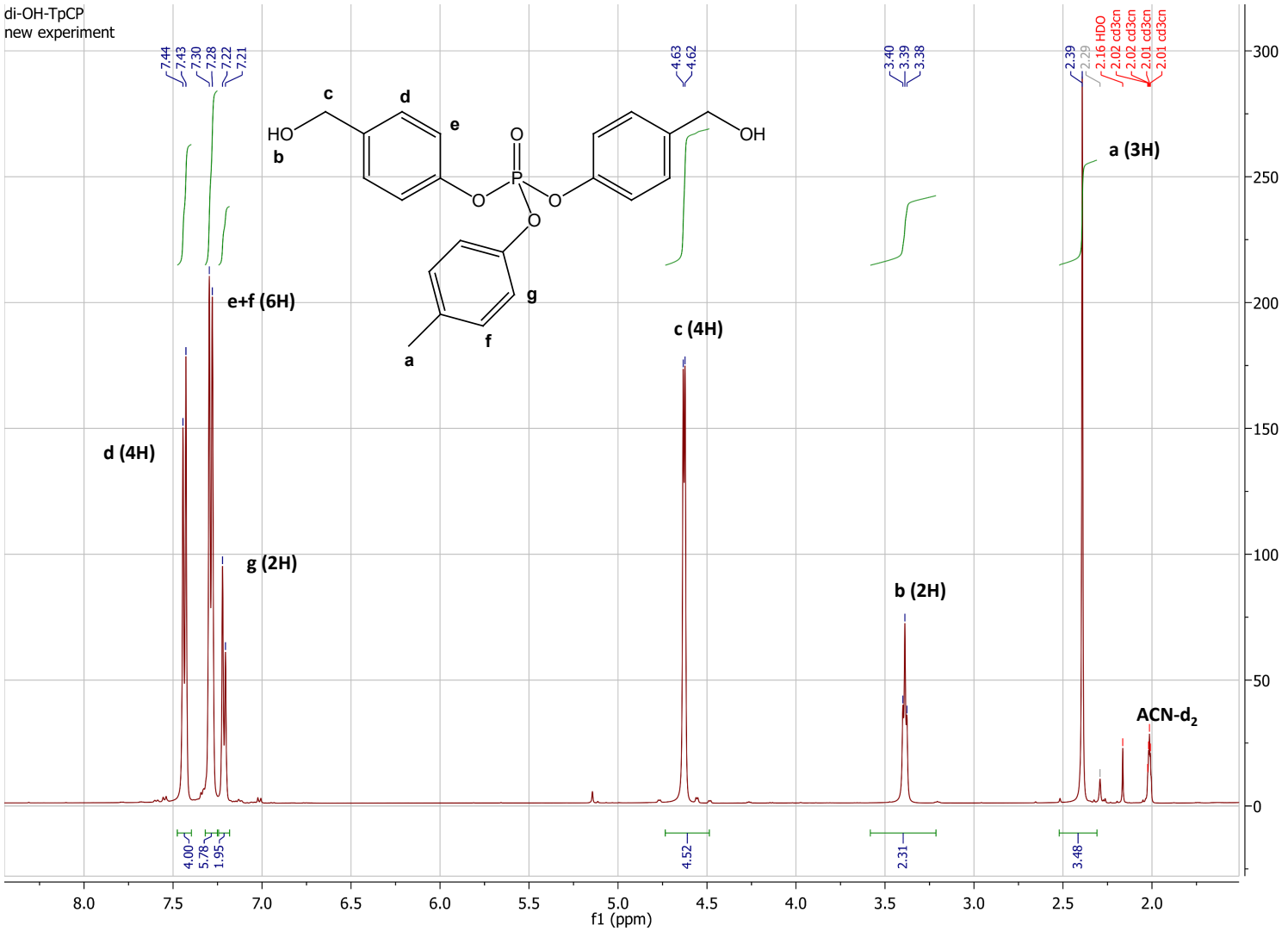




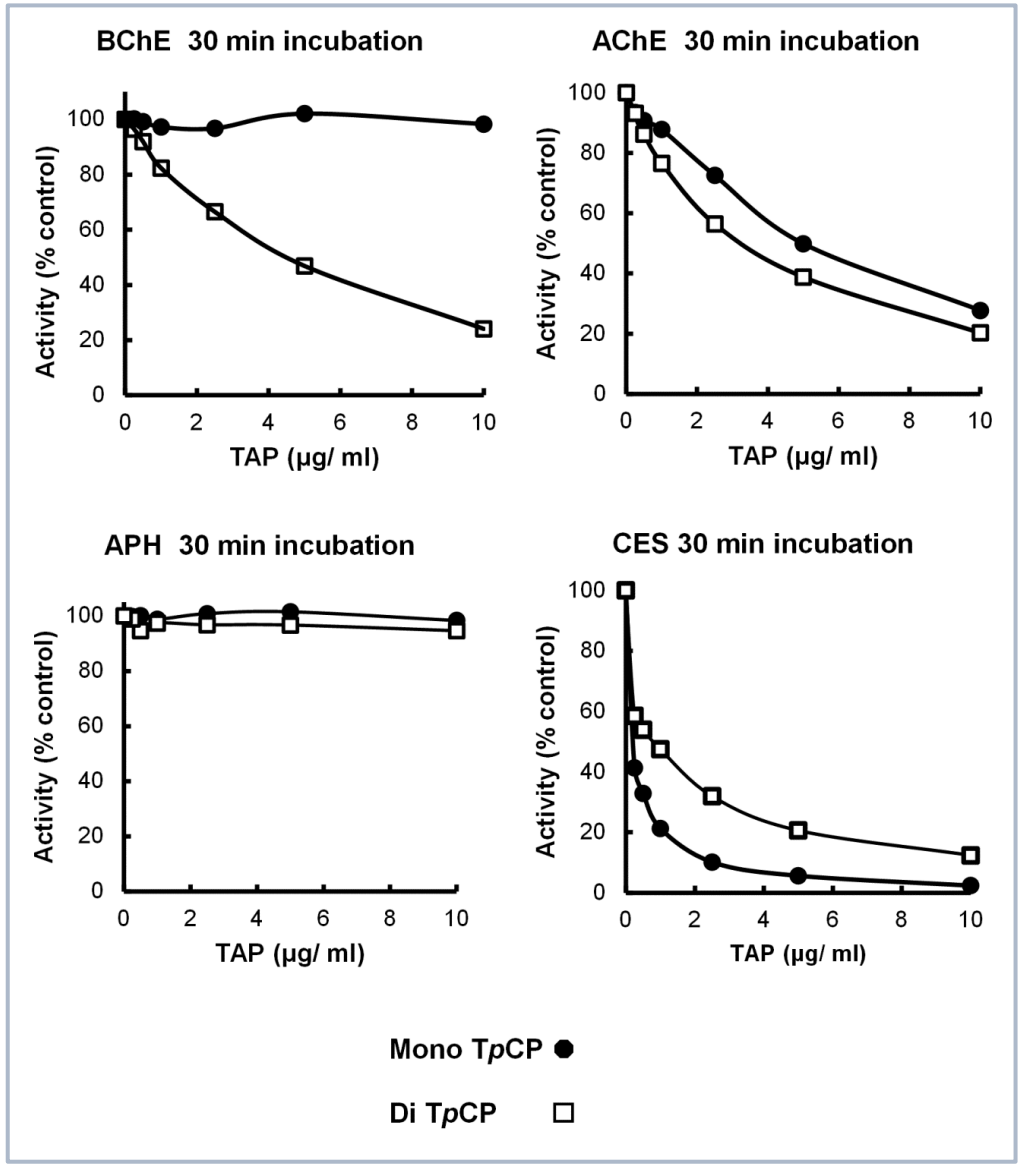
Dr. Matt McDonald

Matt investigated the metabolism of T*p*CP and determined that it was hydroxylated by CYP3A4 generating two metabolites, mono- and di-hydroxy Me metabolites. He then synthesized and characterized both. Inhibition of 4 potential biomarker proteins is shown below

^{1}H-NMR Spectrum of di-OH-Me-T*p*CP



Inhibition of Biomarker Proteins by TpCP Metabolites



Summary

- **Characteristics of a useful blood biomarker protein:**
  - Sensitive to inhibition by TAPs
  - Long half-life in blood
  - Reasonably abundant in blood
  - OP adduct to active site serine remains stable over time
- **Antibodies to the specific proteins allow for rapid biomarker purification and characterization of triaryl phosphate adducts on the active site serine residues of the potential biomarker blood proteins.**
- **Red blood cell AChE appears to be a viable candidate**
  - It has a half life of 33 days
  - It retains the cresyl phosphate residue attached to its active site serine
  - In vitro generated adducts on the active site serine are characterized by mass spectrometric analysis
- Plasma cholinesterase has two problems as a biomarker
  - It has a short half-life (~11 days)
  - The cresyl group falls off over a short period of time (aging) leaving only a phosphate attached to serine
- Genetic variability and more so the sensitivity to inhibitors and inducers of CYP3A4 may explain some of the interindividual sensitivity to TAP exposure with greater influences on activity from foods and drugs.
- Naringenin (from grapefruit) inhibits the generation of toxic metabolites from commercial TAPs
  - It's not yet known if this will be beneficial or not as a treatment for exposure

clem@uw.edu

Support for Biomarker Research

NIH (NIEHS) RO1
NIH (NIEHS) Super Fund Basic Research Grant
CDC Supplement to Super Fund Basic Research Grant
NIH (NIEHS) Children's Health Center UW
Pilot and Crew Unions
Connie Furlong
Royal Australian Air Force
NYCO

Papers published

- Furlong CE, Cole TB, MacCoss M, Richter R, Costa LG. 2005. Biomarkers for Exposure and of Sensitivity to Organophosphorus [OP] Compounds. Proceedings of the BALPA Air Safety and Cabin Air Quality International Aero Industry Conference. Reports in Safety and Environmental Science, School of Safety Science, The University of New South Wales
- Schopfer LM, Furlong CE, Lockridge O. 2010. Development of diagnostics in the search of an explanation for toxic airline syndrome. Anal Biochem 404(1):64-74. PMID 20447373, PMCID: PMC2900449
- Kim JH, Stevens RC, MacCoss MJ, Goodlett Dr, Scherl A, Richter RG, Suzuki SM, Furlong CE. Identification and Characterization of Biomarkers of Organophosphorus (OP) Exposures in Humans. Adv Exp Med Biol 660:61-71. PMID: 20221871.
- Marsillach J, Richter RJ, Kim JH, Stevens RC, Maccoss MJ, Tomazela D, Suzuki SM, Schopfer LM, Lockridge O, Furlong CE. Biomarkers of organophosphorus (OP) exposures in humans. Neurotoxicology. 2011 Oct;32(5):656-60.
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- Furlong CE. Exposure to Triaryl Phosphates: Metabolism and Biomarkers of Exposure. J Biol Phys Chem 11:165-171.
- Marsillach J, Hsieh EJ, Richter RJ, MacCoss MJ, Furlong CE. Proteomic analysis of adducted butyrylcholinesterase for biomonitoring organophosphorus exposures. Chem Biol Interact.
- Baker PE, Cole TB, Cartwright M, Suzuki SM, Thummel KE, Lin YS, Co AL, Rettie AE, Kim JH, Furlong CE. 2013. Identifying safer anti-wear triaryl phosphate additives for jet engine lubricants. Chem Biol Interact 203(1):257-64.
- Marsillach J, Hsieh EJ, MacCoss MM, Costa LG, Furlong CE. 2012.Protein adducts as biomarkers of exposure to organophosphorus compounds. Toxicology 307:46-54.
- Soelberg S, Furlong C (2013) Biosensors and Bioassays for Ecological Risk Monitoring and Assessment. In: Environmental Toxicology (Laws, E. A., ed.), pp 121-142: Springer New York.

Presentations to Increase Awareness of the Cabin Air Issue

- Furlong CE, Soelberg SD, Chinowsky T, Geiss G, Spinelli CB, Stevens R, Near S, Kauffman P, Yee S. 2005. A surface plasmon resonance (SPR)-based sensor system for real-time monitoring of analytes that range in size from small organics to whole cells. Sensors for the aircraft cabin environment. FAA Center of Excellence for Airliner Cabin Environmental Research. 2005. Workshop on: Sensors for the Aircraft Cabin Environment. Boeing, Everett, WA January 19th & 20th
- Furlong CE. Biomarkers for exposure to organophosphorus (OP) compounds. Contaminated Air Protection Conference. Imperial College, London, England, April 21 & 22, 2005.
- Furlong, CE. Biomarkers of Exposure and Sensitivity to Organophosphorus [OP] Compounds. The Annual International Aircraft Cabin Safety Symposium, February 12-15, 2007. Torrance, CA.
- Furlong, CE. Biomarkers of Exposure and Sensitivity to Organophosphorus [OP] Compounds and Consequences of Exposure. Global Cabin Air Quality Executive Meeting 5&6 March, 2007, University College, London, UK (Invited Speaker)
- Furlong, CE. NIEHS. Adventures in Research Translation. EHS Core Center Annual Meeting & Translational Research Workshop. Oregon State University, Corvallis, OR. October 16th, 2007 (Invited Speaker)
- Furlong, CE. Adventures in Research Translation. SBRP 20th Anniversary Celebration, Washington Duke Inn, Durham, NC. Dec. 3-5, 2007.
- Furlong, CE. Biomarkers of Exposure to TCP. 2007 Flight International Crew Management Conference. Brussels, December 6, 2007.
- Furlong, CE. Meetings with members of Parliament, London, UK, December 11, 12. Discussions of OP (TCP) exposures in pilots, crew and passengers. See House of Lords Report: http://www.publications.parliament.uk/pa/ld/ldsctech.htm;
- Written comments provided: http://www.publications.parliament.uk/pa/ld200708/ldselect/ldsctech/7/7we10.htm
- Furlong CE. Exposures and disease risks associated with genetic variability in human plasma paraoxonase (PON1) and biomarkers of exposure. Environmental and Occupational Health Sciences, Superfund Basic Research Project (SBRP). January 17th, 2008. University of Washington.
- Furlong CE. Exposures to tricresylphosphate. SBRP-WETP Technical Workshop on Reducing Risk and Protecting Public Health through Research and Training. April 3-4, 2008. NIH, Bethesda, MD.
- Furlong CE. Exposures to Tricresyl Phosphate. GCAQE Annual Information Exchange and Update. May 20-21, 2008. London, UK.
- Furlong, CE. Biomarkers of Exposure & Paraoxonase 1 as a Biomarker of Susceptibility to Environmentally-Induced Diseases. ATSDR, Atlanta, GA, October 15, 2008. (Invited Speaker)
- CE Furlong, M MacCoss, D Goodlett, AC Sherl, TB Cole, RJ Richter, JH Kim. Blood tests for documenting exposures to pyrolyzed jet engine oils. Aerospace Medical Association 80th Annual Scientific Meeting, Westin Bonaventure Hotel, Los Angeles, CA, May 3-7, 2009
- Furlong CE. Exposures to Tri Aryl Phosphates. GCAQE Annual Information Exchange and Update. April 28-29, 2009. London, UK.

Presentations Continued

- Furlong CE. Organophosphates and Human Health – Airliner Cabin Air Contamination. AOAC International Pacific Northwest Section June 17, 2009, Tacoma, WA. (Keynote address).
- Furlong CE. Organophosphate Exposures and Human Health (Insecticide exposures). AOAC International Pacific Northwest Section June 17, 2009, Tacoma, WA. (Invited speaker).
- Furlong CE. Detection of and Protection against Chemical Threats. Defense Threat Reduction Agency. July 21, 2009. Fort Belvoir, VA.
- Furlong CE. Genetic Variability in Susceptibility to Exposures. Research Advisory Committee on Gulf War Veterans Illnesses. November 2, 2009, Washington, DC.
- Marsillach J, Richter RJ, Kim JH, Stevens RC, MacCoss MJ, Tomazela D, Suzuki SM, Schopfer LM, Lockridge O, Furlong CE. Biomarkers of Organophosphorus (OP) Exposures In Humans. 26th International Neurotoxicology Conference. June 6-10, 2010. Portland, Oregon (platform and poster).
- Furlong CE, Toby B. Cole TB, Karen L. Jansen KL, Rebecca J. Richter RJ, Theo K. Bammler TK, Richard P. Beyer RP, Fred Farin F, Lucio G. Costa LG. Genetic variability factors in human susceptibility to organophosphorus compounds. XII International Congress of Toxicology, Barcelona, 19-23 July, 2010.
- Furlong CE, Richter RJ, Jarvika GP, Checkoway H, Samii A, Costa LG, Griffith A, Roberts JW, Yearout D, Zabetian CP, Ticozzi N, LeClerc AL, Keagle P, Glass JD, Wills A-M, van Blitterswij M, Bosco DA, Rodriguez-Leyva I, Gellera C, Ratti A, Taroni F, McKenna-Yasek DM, Sapph PC, Silani V, Brown Jr RH, Landers JE. Paraoxonases and Neurological Diseases. Fourth International Conference on Paraoxonases, La Pineda, Spain, September 7-10, 2010.
- Baker PE, Cole TB, Thummel KE, Lin YS, Co AL, Rettie AE, Kim JH, Furlong CE. A Rapid Screening Protocol for Identifying Less Toxic Additives for Jet Engine Lubricants. Superfund Basic Research Annual Meeting, Portland, OR, Nov. 10, 2010 (Poster)
- Furlong CE. Biomarkers of Organophosphate Exposure: UW/CDC-ATSDR Collaboration. Superfund Basic Research Program Annual Meeting, November 10-12, 2010, Portland, Oregon.
- Furlong CE, Marsillach J, Richter RJ, Kim JH, Stevens RC, Tomazela D, Suzuki SM, Schopfer LM, Lockridge O, MacCoss MJ Mass Spectrometric Characterization Of Protein Biomarkers Of Organophosphorus (OP) Exposures. 2010 Chemical and Biological Defense Science and Technology Conference Orlando, Florida, 15-19 November 2010.
- Furlong CE, Marsillach J, Richter RJ, Kim JH, Stevens RC, Tomazela D, Suzuki SM, T Cole, Baker P, Schopfer LM, Lockridge O, MacCoss MJ. Biomarkers of organophosphate exposure. Gordon Research Conference: Chemical & Biological Terrorism Defense: Basic Science as a Foundation for the Development of Countermeasures. March 20-25, 2011, Ventura, CA
- Furlong CE, Marsillach J, Richter RJ, Kim JH, Stevens RC, Tomazela D, Suzuki SM, Schopfer LM, Lockridge O, MacCoss MJ. Mass spectrometric characterization of protein biomarkers of organophosphorus (op) exposures. AOAC, Tacoma, WA, June 21, 22, 2011
- Furlong CE. Aircraft cabin air and other OP exposures. Dept. Genome Sciences Retreat, Leavenworth, WA. September 21-23, 2011.
- Furlong CE. Three Decades of Adventures in Research Translation. (Keynote talk) Pacific Northwest Association of Toxicologists (PANWAT) Meeting, Bonneville, WA. Oct. 6-8, 2011.
- Furlong CE. Portable Biosensor Systems for Detection of Toxins, Microbes, Viruses and Allergens. USDA. Western Regional Research Center. March 16, 2012

Presentations Continued

- Hsieh, EJ., Marsillach, J., Richter, RJ,. MacCoss, MJ., Paulsen, MH., Simpson, CD., Furlong, CE. Mass Spectrometry Based Biomarker Analysis of Organophosphorus Exposure in Agricultural Workers. Vancouver, Canada. May 20-24, 2012.
- Furlong CE. Tri-Aryl Phosphate Exposures from Engine Lubricant Anti-Wear Additives. Meeting with the CIAM, GosNIIGA & Interstate Aviation Committee Specialists, National AeroSpace Consulting, Ltd. Moscow, Russia June 1, 2012.
- Marsillach J. Biomarkers of Tri aryl phosphate exposure. Meeting with the CIAM, GosNIIGA & Interstate Aviation Committee Specialists, National AeroSpace Consulting, Ltd. Moscow, Russia. June 1, 2012.
- Furlong CE, Cole TB, Megan Cartwright M, Stephanie M. Suzuki SM,Thummel KE, Lin YS, Co AL, Rettie AE, Kim JH, Baker PE. Tert-Butylated Triaryl Phosphates Are Not Readily Metabolized to Serine Esterase Inhibitors, 11th International Meeting on Cholinesterases. Kazan Russia, June 4-9, 2012.
- Marsillach J, Hsieh EJ, Richter RJ, Cole TB, Kim JH, MacCoss MJ, Tomazela D, Suzuki SM, Baker PE, Paulsen MH, Simpson CD, Schopfer LM, Lockridge O, Furlong CE. Butyrylcholinesterase as a human biomarker for organophosphorus exposure. 11th International Meeting on Cholinesterases. Kazan Russia, June 4-9, 2012
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Occupational Medicine and Contaminated Air Exposures – Quarter Decade Later

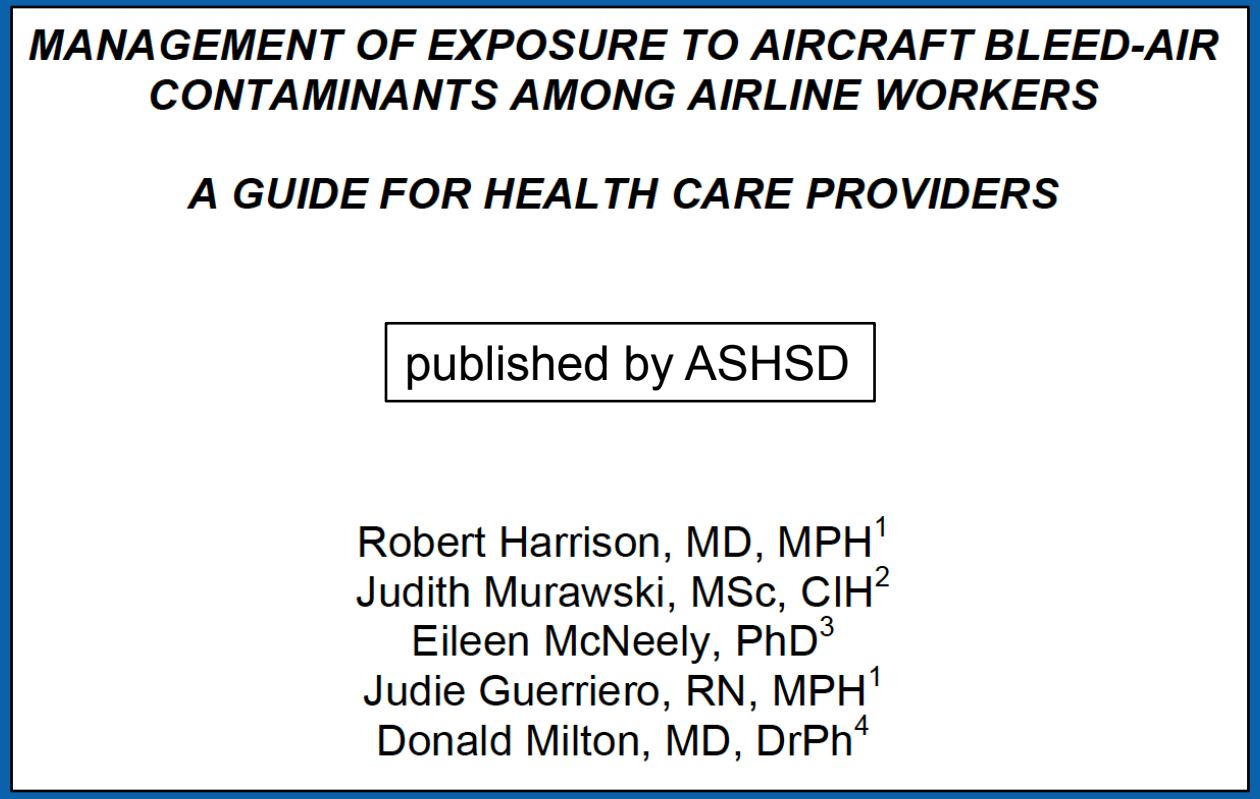
Robert Harrison

Division of Occupational and Environmental Medicine

University of California San Francisco (UCSF)

International Aircraft Cabin Air Conference 2021

Online, 15 – 18 March 2021



http://ashsd.afacwa.org/docs/hcpfull.pdf

The **Association of Flight Attendants-CWA** fights exclusively to improve conditions that affect the safety, health and security of flight attendants. The AFA-CWA **Air Safety, Health and Security Department (ASHSD)** provides full-time staff support in Washington, DC for the AFA-CWA Safety Committee chairs and members and is responsible for solving problems that cannot be solved at the carrier level.

An *acute* health problem due to bleed air contaminant exposure should be considered if these factors are shown to be present:

- There is *either* a documented exposure to bleed air contaminants (based on evidence in the mechanical records, incident reports, or airborne measurements) *or* a history of flying on aircraft type(s) documented to have an increased risk of air supply contamination events;

  and

- Initial symptoms occur within 48 hours following exposure;

  and

- There is objective documentation of acute and/or persistent respiratory, neurological, systemic, or psychiatric symptoms that follow exposure to bleed air contaminants; see Tables 4 and 5.

TABLE 4: ACUTE SYMPTOMS FOLLOWING EXPOSURE TO CONTAMINATED BLEED AIR

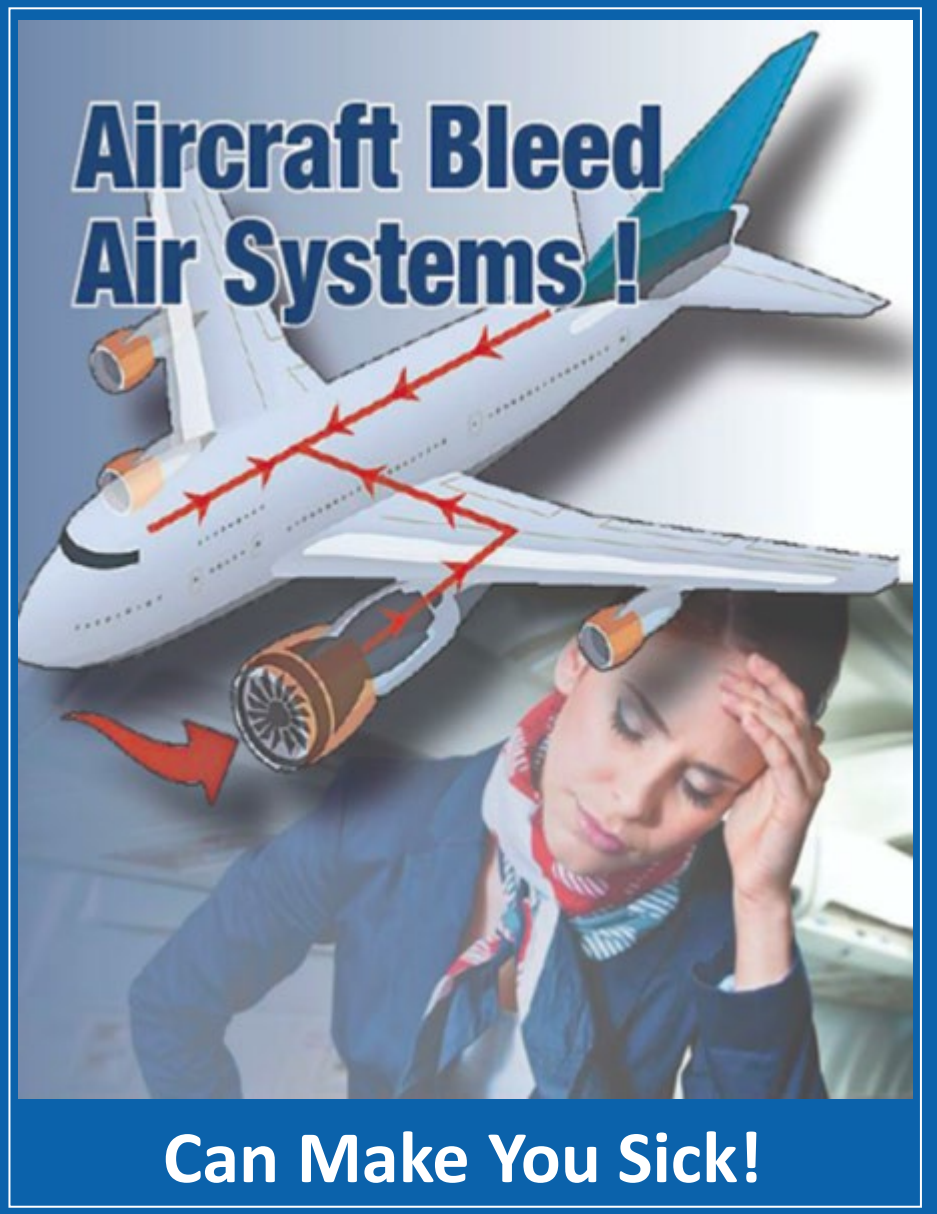
Respiratory	Neurological	Systemic	Psychiatric	Dermal
Cough	Headache	Nausea, vomiting	Anxiety	Rash
Shortness of breath	Dizziness	Fatigue	Sleep disturbance	
Chest tightness	Lightheadedness	Muscle weakness	Depression	
Wheezing	Memory impairment	Palpitations	PTSD	
Eye, nose or throat irritation	Concentration difficulty	Diarrhea		
	Visual changes			
	Tremor			
	Gait problems			
	Paraesthesias			
	Balance problems			
	Slowed mental processing			
	Difficulty multi-tasking			

TABLE 5: CHRONIC SYMPTOMS FOLLOWING EXPOSURE TO CONTAMINATED BLEED AIR

Respiratory	Neurological	Systemic	Psychiatric	Dermal
Cough	Headache	Nausea, vomiting	Anxiety	Rash
Shortness of breath	Slowed mental processing	Fatigue	Sleep disturbance	
Chest tightness	Difficulty multi-tasking	Muscle weakness	Depression	
Wheezing	Memory impairment	Palpitations	PTSD	
	Concentration difficulty	Diarrhea		
	Visual changes			
	Tremor			
	Gait problems			
	Paraesthesias			
	Balance problems			

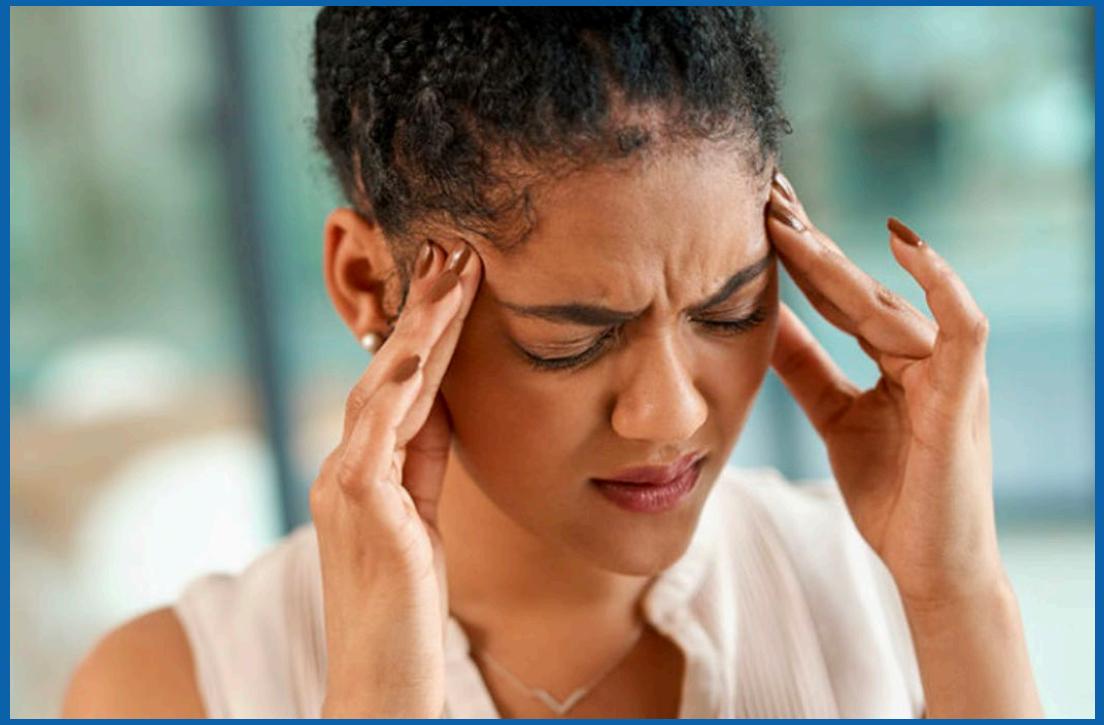
Exposure Assessment

- Industrial hygiene/exposure levels
- Mechanical records
- Incident reports



Headache

- Similar to migraine
- Weeks to months
- Prescription: abortive agents (NSAIDs, acetaminophen, triptans, lasmiditan, ergots), preventive treatment (beta blockers, calcium channel blockers, tricyclic antidepressants, anticonvulsants, CGRP antagonists)



NSAID: Nonsteroidal Anti-Inflammatory Drugs

CGRP stands for Calcitonin Gene-Related Peptide, and it is a protein that is released around the brain. When CGRP is released, it causes intense inflammation in the coverings of the brain, and for most migraine patients, causes the pain of a migraine attack.

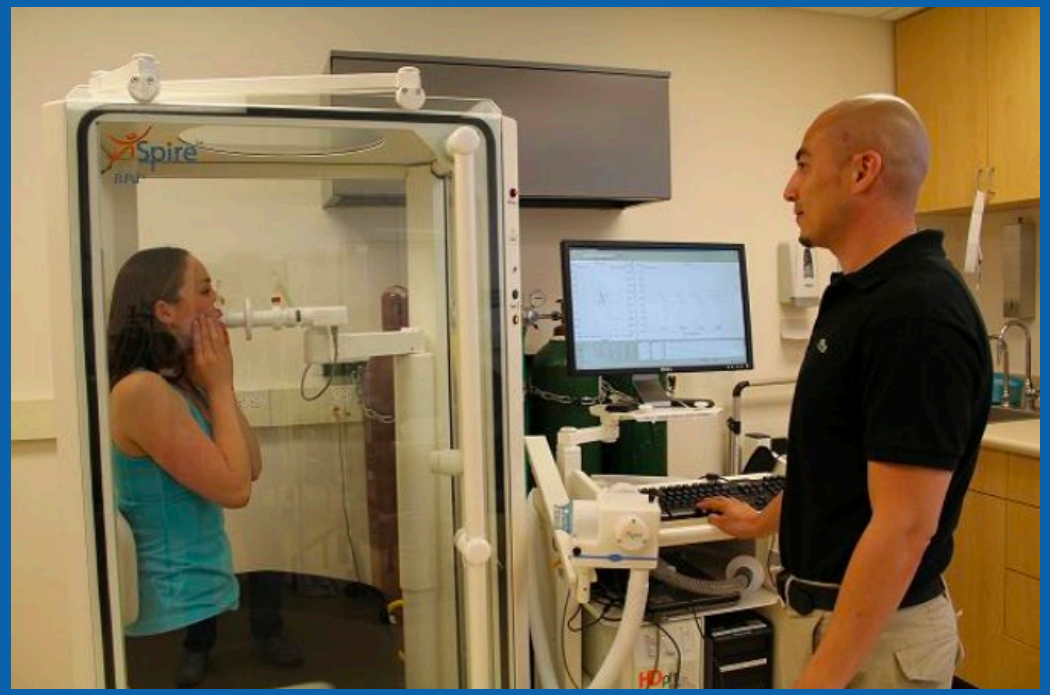
Cognitive Deficits

- Memory, word finding and concentration problems; personality changes
- Neuropsychological testing to determine brain injury from psychological sequelae



Irritant-Associated Asthma

- Acute versus chronic inhalation exposure
- Shortness of breath, chest tightness, wheezing
- Diagnosis : PFTs, methacholine challenge
- Prescription : stepwise approach (GINA)



PFT: Pulmonary Function Test

GINA: Global Initiative for Asthma

Los Angeles Times

‘WE ARE SLOWLY BEING POISONED’



HOW TOXIC FUMES SEEP INTO THE AIR YOU BREATHE ON PLANES

By Kiera Feldman

December 17, 2020

The article from the
Los Angeles Times archived:

https://perma.cc/CPS4-KHEU

Recommendations

- Standardized medical protocols and diagnostic criteria
- Data tracking to assess scope of problem
- Case follow-up for outcomes

Toxicology of Contaminated Air: Are We Underestimating OP Exposure to Aircrew from Engine Bleed Air?

Professor C V Howard

vyv.howard@gmail.com

Aircraft Cabin Air Conference 2021

Current risk assessment arguments

- Consider single compounds and apply OELs to determine safety
  - This ignores the mixture effect. OELs are inappropriate
- Only take into account vapour concentrations of contaminants in engine bleed air, one at a time
  - This ignores other sources of exposure – e.g .particulate aerosols
- Don’t take account of ‘dose’ – accumulated over time
  - This ignores chronic repeat low-dose exposure over thousands of hours
- Assume that any adverse effects are totally reversible
  - This ignores the large scientific literature showing that some effects of OPs are irreversible, therefore the adverse effects are cumulative

Mi

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key to the Researchers

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Inappropriate Use of Risk Assessment in Addressing Health Hazards Posed by Civil Aircraft Cabin Air

C V Howard*

Centre for Molecular Biosciences, University of Ulster, UK

Submission: February 12, 2020; **Published:** February 27, 2020

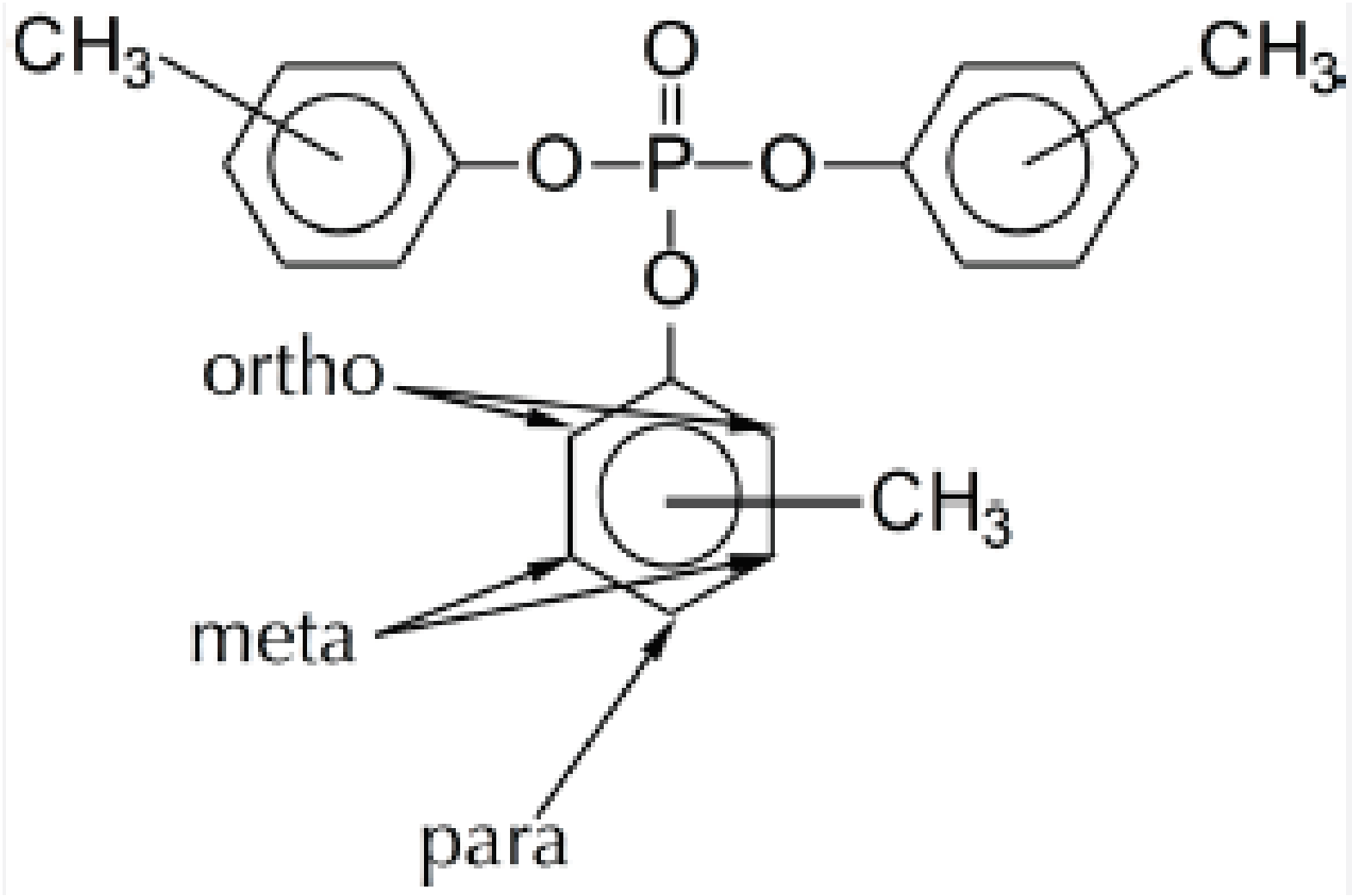
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Abstract

Over decades, the airline industry has published considerable documentation on the potential for inhalation exposure to organophosphates and other toxins sourced to engine oil fumes supplied by "bleed air" systems, which are used on most commercial and military aircraft. Case studies on the subsequent development of neurological and other symptoms reported by crewmembers have also been widely documented. However, airline industry reviews tend to define toxicity of engine oil fumes according to a single toxicological endpoint - Oragano Phosphate Induced Delayed Neuropathy (OPIDN) – which is acknowledged to be the result of a very high dose of exposure to a specific chemical, tri-ortho cresyl phosphate (TOCP). Industry reviews typically argue that the low levels of TOCP in aviation engine oils justifies the safety of continuing to use unfiltered engine bleed air to ventilate civil and military aircraft cabins. In fact, this approach ignores the routine presence and toxicity of a complex mixture of OPs in oil fumes supplied by engine bleed air systems and ignores the type of neurological symptoms that crews report (i.e., not OPIDN). The industry approach also ignores the scientific literature on repeated low-dose exposure to OPs over extended periods (particularly relevant for airline crewmembers) and the variable susceptibility of individuals to toxicological damage. This paper reviews the above-mentioned studies and presents the scientific literature that should be considered to make a realistic risk assessment of the hazards of aircraft engine bleed air.

Keywords: Neurological symptoms; Cresols; Phenols; Cresyl phosphate

Cresyl phosphate isomers



Comparative abundance of cresyl phosphates

Ortho isomer	ppm in oils
TOCP	0.005
DOCP	6
MOCP	3070
TOTAL PPM	3076

Comparative toxicity of cresyl phosphates

Winder C, Balouet JC (2002) The toxicity of commercial jet oils. Environ Res 89(2): 146-164.

Isomer	Concentration		Toxicity	
	Absolute (ppm)	Relative to TOCP	Relative to TOCP	Equivalent
TOCP	0.005	1	1	1 x
DOCP	6	1,200	5	6,000 x
MOCP	3070	614,000	10	6,140,000 x
			Total	6,146,001 x

OPIDN – OrganoPosphate Induced Delayed Neuropathy

- Came about because a medicine in the US called Ginger Jake was illegally adulterated with TOCP.
- Many people received very high oral doses of TOCP
- Symptoms of paralysis, neuropathy, central CNS effects and death ensued.
- Admitted to be the result of extremely high exposure
- Aertotoxic Syndrome does not present the same clinical picture as the original OPIDN description, though there are clearly some aspects in common

Studies using OPIDN as an endpoint – Part1

Table 3: Toxicological assessment studies.

Study	Toxicological endpoint	Compounds considered	Mixtures considered	OELs used	Route of exposure
Freudenthal, 1993 [20]	OPIDN	TCP, TOCP	No	No	Oral (hen)
Daughtrey, 1996 [29]	OPIDN	TCP,TPPT, BTP	No	No	Oral (hen)
Weiner & Jortner, 1999* [30]	OPIDN	TAPs, TCP, TOCP	No	No	Oral/dermal
Craig & Barth, 1999 [27]	OPIDN	TOCP/MOCP/O- isomers	No	Yes	Oral/dermal (hen/cat)
Mackerer, 1999 [3]	OPIDN	TCP/ meta/paraisomers, OCP /TAPs **	No	No	Oral (hen/rat)
Daughtrey, 2006 [31]	OPIDN	Oil, TOCP	No	No	Oral (hen)
De Ree, 2014* [32]	OPIDN	TOCP	No	Yes	Oral (Chicken/ cat)
CAA, 2004* [33]	OPIDN	TOCP	No	Yes	oral (chickens)

Studies using OPIDN as an endpoint – Part 2

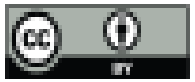
De Boer, 2015* [34]	OPIDN	TCP, TOCP	Yes	Yes	
Pleus,2012*/2015*/2019* [35-37]	OPIDN	TOCP	No	Yes	
Wolkoff, 2015* [38]	OPIDN	TOCP/VOCs/ozone/RH	Yes	Yes	
Airbus & UK House of Lords 2000* [39]	OPIDN	TOCP	No	Yes	
COT, 2013* [40]	OPIDN	TOCP	No	Yes	
Bagshaw, 2015 * [41]	OPIDN	TOCP	No	Yes	
EASA, 2017 [pyrolysis] [7]	OPIDN	TOCP/oils/various	No	Yes	
Costa, 2018* [42]	OPIDN/AChE	TCP/TOCP	No		
Schuchardt, 2018 * [43]	OPIDN	TCP, TOCP, VOCs...	No	Yes	

* Risk assessment undertaken based on other studies

** Complex mixtures of methyl phenols (cresols) dimethyl phenols (xylenols), phenol, other alkylated phenols, and small amounts of unidentified impurities.

Particles as a source of exposure to OPs

Atmos. Chem. Phys., 19, 6389–6399, 2019
https://doi.org/10.5194/acp-19-6389-2019
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Atmospheric Chemistry and Physics
Open Access
EGU

Identification of jet lubrication oil as a major component of aircraft exhaust nanoparticles

Akihiro Fushimi[1], Katsumi Saitoh[1,2], Yuji Fujitani[3], and Nobuyuki Takegawa[4]

Abstract. Jet engine aircraft are ubiquitous and significant sources of atmospheric nanoparticles. Using size-resolved particulate samples collected near a runway of the Narita International Airport, Japan, we clearly demonstrate that organic compounds in the ambient nanoparticles (diameters: < 30 nm) were dominated by nearly intact forms of jet engine lubrication oil. This finding provides direct evidence for the importance of unburned lubrication oil as a source of aircraft exhaust nanoparticles and also has an implication for their environmental impacts near airports and in the upper troposphere.

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Howard CV, et al. J Nanomed Nanosci: JNAN-139.

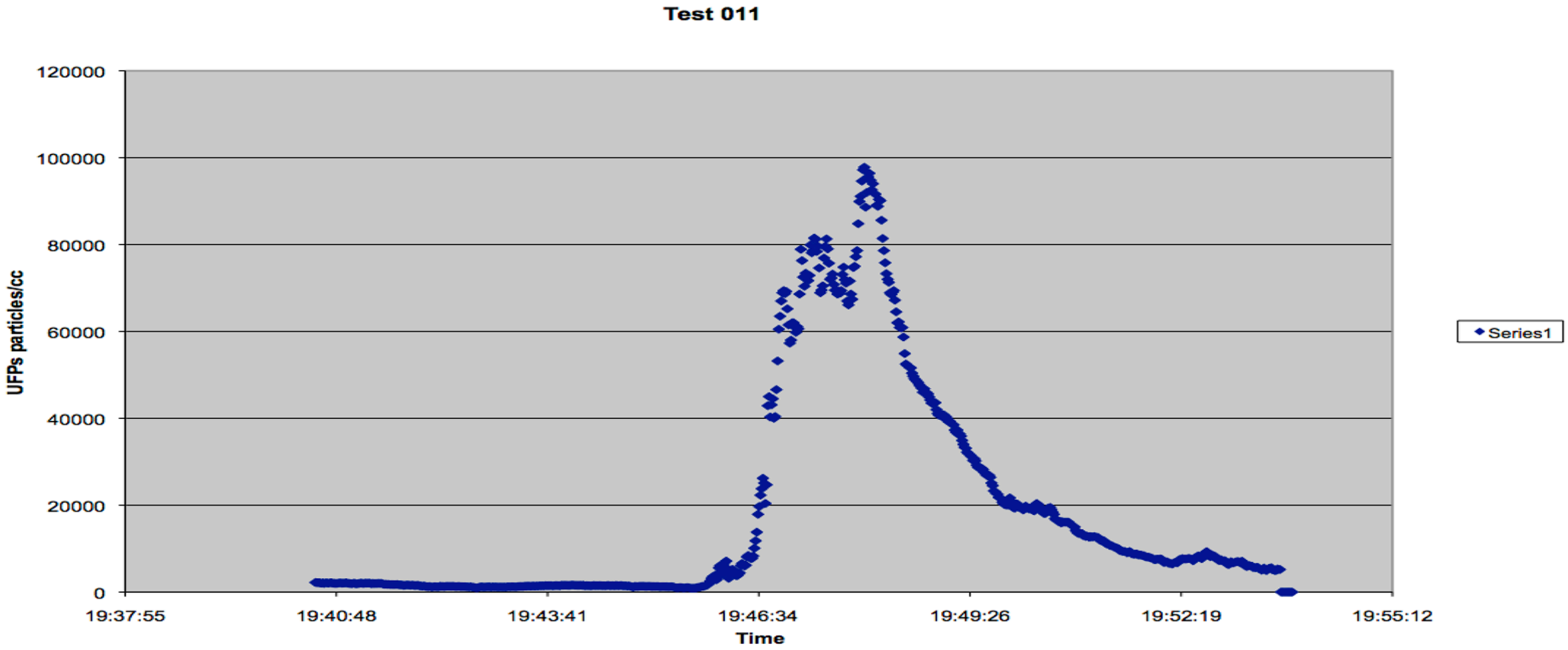
Review Article

DOI: 10.29011/JNAN-139. 100039

Is a Cumulative Exposure to a Background Aerosol of Nanoparticles Part of the Causal Mechanism of Aerotoxic Syndrome?

C. Vyvyan Howard[1*], David W. Johnson[2], John Morton[3], Susan Michaelis[4], David Supplee[5], Jonathan Burdon[6]

Particulate aerosols present in aircraft



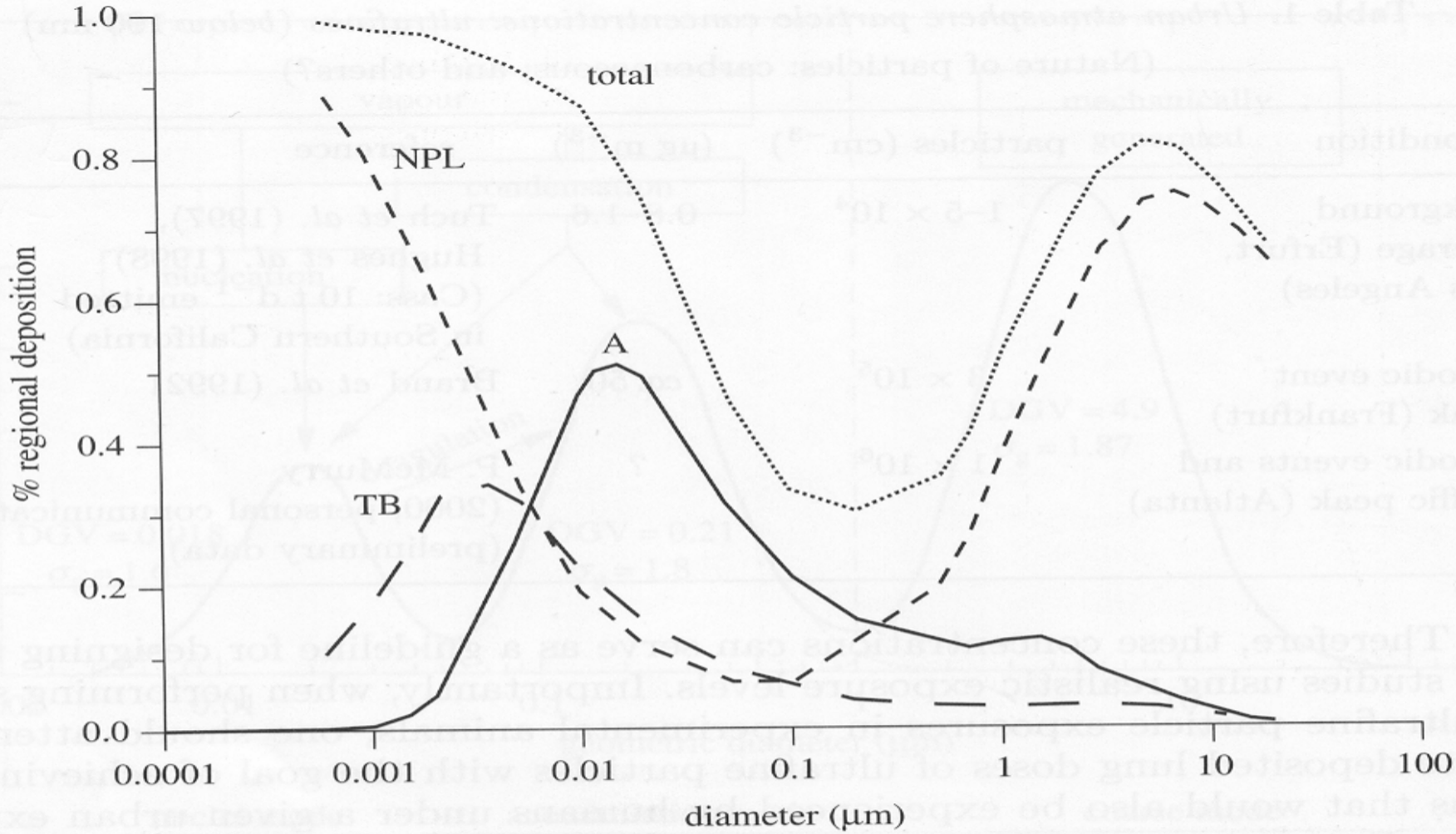


Figure 6. Predicted deposition of inhaled particles of different sizes of unit density in the human respiratory tract during nose breathing, light exercise (ICRP 1994). 'NPL' denotes nasopharyngolaryngeal deposition; 'TB' denotes tracheobronchial deposition; 'A' denotes alveolar deposition; 'total' denotes the sum of particle depositions in the respiratory tract for all three compartments.

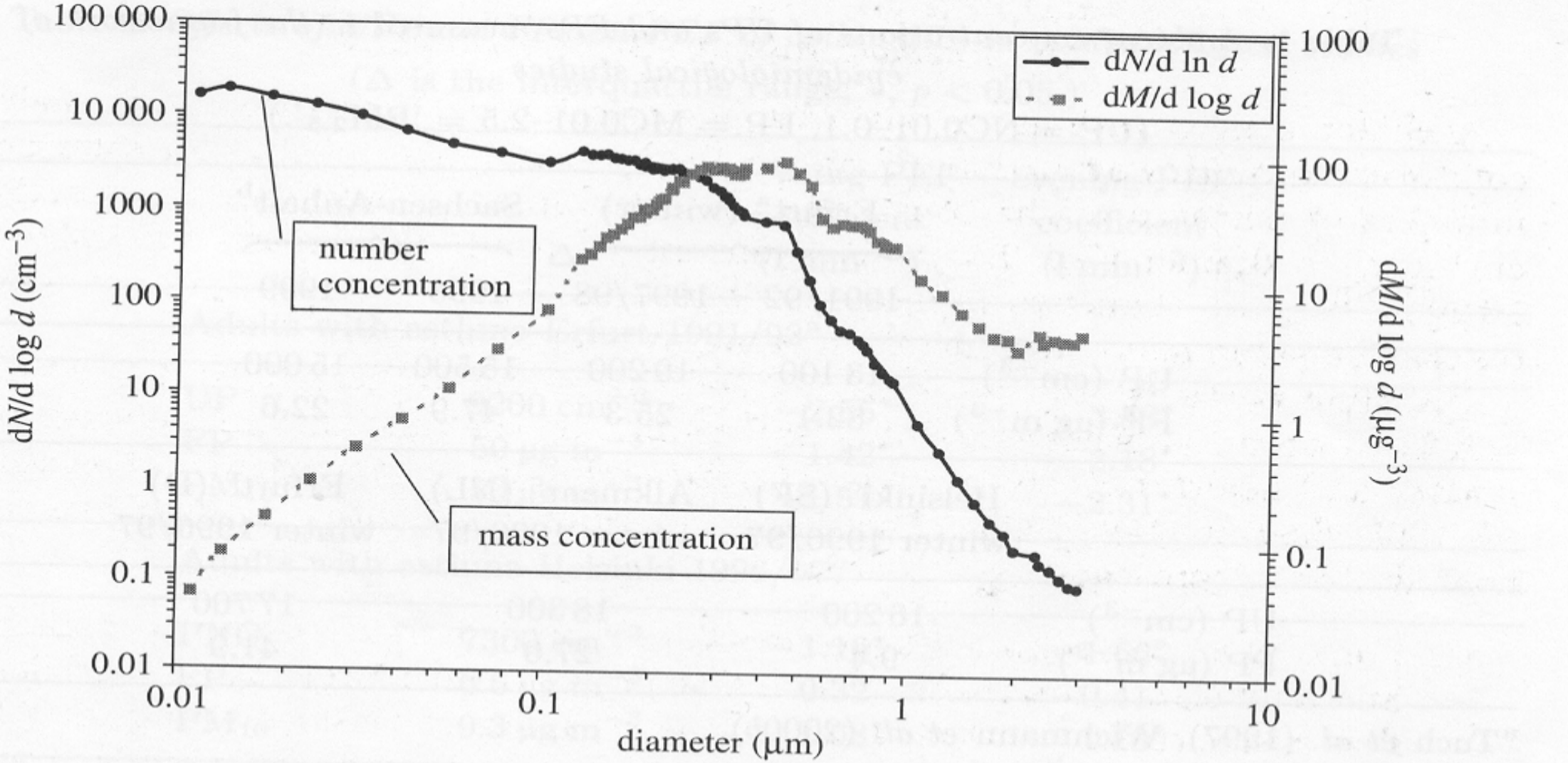


Figure 1. Typical particle number and mass distribution averages from approximately 10 000 single measurements, Erfurt. From Wichmann *et al.* (2000*a*).

Wichmann HE & Peters A (2000). *Phil. Trans. R. Soc. Lond*. *A* **358**: 2751-2769

Risk Assessment

A risk assessment goes through several steps:

a) Hazard identification – which requires insight into the system or process under scrutiny.

b) Hazard assessment – which can only be performed on hazards that have been considered, requires the application of scientific experimentation (e.g. toxicology) and is therefore costly and time consuming

c) Exposure assessment - is required when human exposure to toxic substances is being considered and requires further scientific investigation (e.g. measuring contamination levels). It can be expensive to perform adequately. The route of entry of the toxicant(s) is critical to the exposure assessment.

d) Risk assessment – Finally, the information collected in steps [1–3] can be combined into a risk assessment. The validity of this final step is totally reliant on the rigour and completeness of the earlier steps. Incorrect conclusions can be caused by not choosing the most sensitive toxicological endpoint, not considering the appropriate route of entry of the toxicant into the body, failure to address the problem of mixtures, etc.

Current risk assessments are failing because:

- 1) Hazard identification
  - Exposure to a complex mixture of toxic substances not considered
- 2) Hazard assessment
  - No attempt to assess the hazard of the mixture of OPs in turbine oils
- 3) Exposure assessment
  - No attempt to access the impact of oil droplet aerosols on ‘dose’
- 4(Risk assessment
  - Adoption of an unrealistic toxicological endpoint – OPIDN

Aircraft Cabin Air International Conference 2021 (ACA 2021) – Proceedings

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Conference Director: Tristan Loraine
Publisher: London, UK: GCAQE (https://gcaqe.org)
Editors: Dieter Scholz, Susan Michaelis

How to Win a Claim Arising Out of a Fume Event

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Abstract

This is the story of the first case to prove that the toxic fumes resulting from a fume event can cause permanent neurological damage. The Oregon attorney who won this case describes how he proved this case, and how he had overcome the industry response. The case was proven through the analogy of four links of a chain: factual, scientific, medical and disability. Each link is proven independently, and each link assumes the veracity of the other links. The factual link involves proving that the fume event did happen. The scientific link establishes that these fumes can cause these conditions. Assuming the first two links are proven, the medical link establishes that the pilot's conditions were likely caused by the fume event. The final link proves the resultant impairment. This concept defeated the industry argument that the scientists need to have read the entire medical record to offer an opinion, or that the doctors have to be able to defend the science. The links are independent. Therefore, the doctors are not deferring to the toxicologists. Other arguments included the industry assertion that without knowing the exact dose and composition of the fumes one cannot prove causation and that the only harmful component is the tri-ortho isomer. Scientific testimony established the other components of these fumes are harmful aside from the ortho isomer, and that causation can be proven without knowing the exact dose. The end result was an order from the court establishing that these toxic fumes caused a wide variety of neurological disabilities suffered by the pilot.

Keywords

fume event, OPIDN, legal case, compensation claim, strategy

1 Introduction

About four years ago a commercial pilot for Jet Blue was exposed to a fume event that produced severe injuries. He filed a worker's compensation claim in the State of Oregon. His claim was denied. The appeal of that denial went to trial. The judge overturned the denial and ruled in favor of the pilot.

This was the first case in North America or Europe to establish that these toxic fumes can cause permanent neurological impairment. The attorney who handled this case is a sole practitioner in Oregon who took on the airline industry and won. This is his presentation in which he describes this epic battle, the steps he had to take to prove this case, and the many obstacles he had to overcome to win.

How to cite this paper (ISO 690, Harvard): LASKEN, Glen, 2021. How to Win a Claim Arising Out of a Fume Event. *Aircraft Cabin Air International Conference 2021 (Online, 15-18 March 2021)*. London, UK: GCAQE. Available from: https://doi.org/10.5281/zenodo.4939077
Review process: Editorial review. The corresponding author is marked with *.

I have the unenviable task of summarizing 30 months of litigation into a few pages of a paper 30 minutes, so I will have to leave out most of the humorous anecdotes. And, since I want this to be both entertaining and useful, I will leave out all of the procedural shenanigans that are unique to Oregon Worker's Compensation Law.

Instead, *I will focus on two things: how to prove your case, and, how to defend the castle*. Since we can anticipate what attacks the industry will mount, you can set up your case in such a way as to allow yourself to fend off those attacks. Before we cover that, allow me to set the stage for you.

2 Captain Kirk Myers

Captain Kirk Myers was a Pilot for Jet Blue with over 20 years of experience. He was unfortunately subjected to a rather severe fume event about 4 years ago. When he arrived at Portland International Airport to begin his day, he was advised that the plane he was scheduled to fly had reported a bad smell on its previous flight. He and the FO were directed to spool up the engines while maintenance tried to figure it out.

During three separate 15 minute run ups they were subjected to very bad fumes. This produced immediate and severe symptoms including gagging, twitching and confusion. They were barely able to get off the plane. While the FO quickly recovered, Kirk's symptoms persisted. He called the company doctor that night and was told that he would be just fine. Just take some aspirin, drink some water and get some fresh air. The next morning Kirk thought he felt ok and when they flew to New York that day the FO handled the stick and Kirk handled the radio. Kirk's symptoms unfortunately then ramped up, and that was the last time that he ever flew. He has been disabled ever since.

He filed a worker's compensation claim that was initially vaguely accepted. The insurance company then tried to force him to settle out. When he refused, he and his Portland attorney parted ways, and the insurance company punished him by denying everything and shutting down the claim. Kirk then hired me with the marching orders: win the damn case.

Now, there is a certain sense of clarity that this brings. Knowing that there would be NO settlement meant that no matter how hard things got, there would be no easy bail out with a settlement. This would be a fight to the death. Either go big or go home.

3 The Oregon Attorney

I'm a sole practitioner in a tiny town in the mountains of Oregon. My entire legal team consists of me, my secretary, and my dog Mariposa. I'm taking on AIG Insurances Company and the airline industry. Not surprisingly, they were represented by probably one the largest and best defense firms in our state led by one of their best trial attorneys. What on earth was I thinking? I could just imagine the snickering in the Board Rooms back East: "Why we'll crush this hayseed." I love it when people underestimate me. What they didn't expect is that I'm a Chicago boy, born and raised. There, you learn the lesson, to use the words of Sean Connery in The Untouchables: "You don't bring a knife to a gunfight."

4 That's What You Have to Do: Overwhelm Them!

So, in my trial they bring in two doctors to say that my client is faking, and I counter with seven doctors to say he isn't. They bring in their hired gun from Seattle and I counter with Dr. Abou Donia, Dr. Kannecki, and Dr. Harrison. They assert that we don't really know what happen that day—or if there even was a fume event at all, and I fly in Dr. Michaelis to explain to the court exactly what happened that day. They deride us about the research in their opening statement: "Gee, Dr. Harrison says he has read over a hundred papers, well where are they, how do we really know what they say?" So I counter on day two of trial by wheeling in a hand truck with bankers boxes for the me, the judge and opposing counsel, containing in chronological order over 120 scientific studies and papers from the 1940s to 2020. Over 2600 pages complete with summaries of each one including every study cited by their expert. You should

have seen defense counsel's face turn green when I handed him his box. And, for good measure, I flew in Judith Anderson to testify in trial about this science. That's what you have to do. Overwhelm them. You can't wing it, or do what you think is just barely enough. It's all or nothing for us. We have to win by three touchdowns or, since most of you are not in the US, you have to win by 5 goals.

Here is the other thing about little old me taking on this army. This isn't a bar fight that you can't win, with 6 guys beating you with pool cues all at once. This is a legal bar fight, with rules that require the defense to trot out one attorney at a time to do opening, direct cross, and summation. Like the Roman legend of Horatius at the bridge who singlehandedly held off the invading army one soldier at a time, one well prepared lawyer can take on and defeat an army of lawyers.

The end result is that we won everything. The judge ordered them to accept toxic encephalopathy, neurocognitive dysfunction, and two visual impairments, saccadic eye movement and convergence insufficiency. So, let's turn to our two main points.

5 How to Build Your Case

I started out by telling the court that my case had two bookends that we will prove conclusively: this fume event happened and Captain Myers is impaired. In between is the scientific and medical causation. I then described that this causation consisted of four links of a chain, each one forged independently, each one necessary, and each one relying on the other links: the factual link of his fume exposure, the scientific link demonstrating that these fumes can cause these harmful effects, the medical causation link, and the impairment link. These links join together to connect our bookends.

Starting with the first link, the factual link, your presentation is driven by the nature of your client's exposure: was this a fume event like I had to work with, is it gradual exposure over time, or some combination of both. Since I had a dramatic fume event with immediate reporting and obvious symptoms, I went with just the fume event. Perhaps I could have also proven that there was the insidious gradual exposure, and the judge's order suggests that I might have succeeded. However, I didn't need to take that chance, especially since I had such good facts. I had some maintenance records, witness statements and testimony. I thought that was enough. I found out that this wasn't enough during the deposition of Dr. Harrison in San Fransisco, when opposing counsel badgered him with questions about the fact that the maintenance records suggested that the APU was the culprit, and yet it wasn't even on during the supposed event. How do we know anything really happened etc., etc., etc. At that point of the litigation I didn't even know what the APU was. I realized that if I don't understand this, how am I going to persuade the judge. That's what led me to consult with Dr. Michaelis and later fly her to Oregon to explain to the court that the APU and the engines share common ductwork which had become soiled by the APU. So, even though the APU was off during the runoff, the air from the engines passed through this contaminated duct work, which led to the fume event. By the time she was done testifying, opposing counsel was left with starting his cross examination by saying to the court, "Well, I guess we know exactly what happened, so let's move on to something else."

The second link in the chain is the scientific causation link. These fumes can and have caused these problems. Provide scientific analysis of where and how the body is attacked from a chemical and psychological standpoint. Prove this through the research and testing that has been done, and of course with live expert testimony. Perhaps the most important thing here is to remember who you are attempting to persuade. I remember that when I took on this case I had a Grade School level understanding of organophosphates. Over the course of dozens of phone calls over many months, Judith Anderson patiently educated me, pointed me to the research and directed me to other experts. There is no way that I could have won this case without her help. Now, if you are in front of a jury, your quest is to break down this complicated science to that Grade School level and, while you are at it, make it interesting and entertaining so they will remember what you are saying. Believe me, if your expert tells a jury that most organophosphate esters are direct inhibitors of AchE, they will have no idea what you are talking about and they will disregard the testimony.

The third link in the chain is the medical causation link. Establish that it is medically probable that these fumes caused your client's conditions. Provide clear, cogent and concise testimony that is understandable to your judge or jury. Be sure to eliminate all other potential medical explanations for your client's conditions.

The final link in the chain is the impairment link. Be sure to emphasize the objective testing that cannot be faked. We had a pet scan, Dr. Abou Donia's bloodwork, an MRI and a CT scan, visual testing and three separate neuro-psychological tests. If you are trying a personal injury case, this is where you finish up with demonstrating the effect these conditions have had on your clients' quality of life and his economic loss.

Those are the four links of the chain that form your case. Each is necessary, each is independent, and yet each relies on the other links.

6 How to Defend the Castle

I think of my case as a castle being attacked. If they breach any wall they can sack your castle and you will lose your case. You have to defend and defeat every attack. The key to success is to anticipate all the possible attacks on your case. That way you and your witnesses can be prepared.

With that in mind, here is what we faced and how we responded, which should give you a pretty good idea what to expect.

6.1 Attacks on the First: The Factual Link

The nature of the attacks on the factual link will depend on the nature of the exposure you are claiming. For a fume event, you should expect that they will argue that this could never happen and it certainly didn't happen here. Your response is to explain how this could ever happen: where the air comes from and how it becomes contaminated. I highly recommend visual art here. This can be a little animated video showing the circulation of air, or something as simple as the hand written drawing that Susan Michaelis prepared for the court in my case. Remember keep it simple, keep it interesting. Your judge or jury has to understand how this could possibly happen.

The other aspect of the factual link is the evidence of your particular fume event. You will want all the relevant maintenance records, which can be tricky because you should expect the airline to minimize their records and then hide what they do have. You have to do more than send out a subpoena and hope. You need to scrounge around and try to uncover the records for yourself. Then, you will want expert testimony explaining (in simple terms) the significance of those records.

For gradual exposure, expect that their experts will say that there IS no gradual exposure, be prepared to counter this with expert testimony and the research papers that have been done that show that there is a gradual exposure to these fumes.

6.2 Attacks on the Second: The Science Link

For the second link, the science link, you can expect several attacks.

6.2.1 The First Attack: Dose Response, Dose Response, Dose Response

Their experts argued that it is impossible, even irresponsible to claim causation without knowing the exact composition of the fumes and the exact amount of every isomer and nano particle, something you of course cannot do. You should prepare your scientists for this line of questioning.

Dr. Harrison effectively refuted this by observing that there was plenty of evidence from which to render an opinion without exact dosage. He is frankly the best expert witness I have ever seen. When asked a the tough question about his ability to render such a causation opinion without knowing exact doses, he actually thought quietly for a full 20

seconds and then said, “I have a five part answer to that question.” Opposing counsel sagged into his chair so much I thought he was melting.

You should certainly explain that it is the airlines that are preventing this exactitude by refusing to put air monitors on the planes, and that might make that judge or jury angry. But, it won’t win this argument. You need solid affirmative testimony about the ability to render an opinion without knowing the exact dose. In my final summation I used the parable of the dead policeman.

Imagine a burning building. Imagine that the first person on the scene is a policeman. Imagine he hears screams, and he rushes into the building without protective equipment. Imagine he doesn’t make it out alive. Imagine that afterwards, his body is found unburned and quiet dead. Imagine that his heirs file a worker’s compensation claim which is then denied by the insurance company. Imagine that the same industry expert from Seattle testifies that since we don’t know the exact composition of the smoke there is no way to establish causation. Dose response, dose response, dose response. I think that I would be happy to take that case and I’d win that one too.

6.2.2 The Second Predictable Attack: Tri Ortho Isomers and OPIDN

The second predictable attack is their assertion that the only harmful components of the fumes are the tri ortho isomers. Nothing else matters, and the only endpoint to measure is OPIDN (organo phosphate induced delayed neurotoxicity), nothing else matters. This leads to Dr. Jelly Beans, as I call their expert. He is smart, articulate, and quick on his feet, so he is a handful to cross examine. He is also clever, charismatic, handsome and well dressed, so juries love him. Don’t underestimate this guy. He is good. His MO is to bring in a jelly bean and a picture of the space needle in Seattle, and then tell the jury that there is SO little ortho content in the oil now that if the total ortho content was represented by this jelly bean, you would have to fill the entire space needle with these jelly beans to develop OPIDN. Great visual. Bad science. There are two fundamental problems with this.

First, the tri ortho-cresyl phosphate isomer is NOT the only harmful component. What about the di ortho and mono ortho, and the meta and para isomers, what about the nano particles that are formed at high temperatures. What about all the other toxins and the evidence that the effects on the body are worse when hit with several toxins at once. I repeatedly referred to these fumes as a primordial soup of toxins. The Mobile Memos from 1988 and 1990 make clear that measuring ToCP alone is not a reliable indicator in light of the many other toxins in the oil. The MSDS sheets for Mobile II reveal that there are many hazards. The cans of oil themselves contain warnings that TCP can cause nerve damage. This is all compelling evidence since it comes from the oil manufacturer.

Second, OPIDN is not the only possible consequence. In fact, it’s the least likely. Your scientists need to make this point, and back it up with the research that has been done that shows that there are a wide variety of disabling effects aside from OPIDN. The research done by Dr. Abou Donia, Dr. Van Netten, and Dr. Michaelis provides solid evidence of this.

If you really want to win your case, bring in all three to explain their research. I got two out of three. I just couldn’t lure Dr. Van Netten down from Canada. As we heard yesterday, Dr. Howard’s paper from 2020 is exactly on point in refuting the industry logic here. In our trial, Dr. Jellybeans switched it up by using M&Ms to represent the total ortho content, saying that you would have to stack them so high as to reach the space station to have a harmful effect. That led me to open up cross by asking him, “Gee, what happened to the jelly beans? Does that have more jury appeal? Do you think that M&Ms are more suitable for a judge?” After about 10 minutes of this, he had about enough of me, but it did serve to knock him off his skates a little, to use an old hockey term.

I asked him if he regularly testified on behalf of the airlines, and he answered by declaring that he had never testified for Jet Blue before. I then I pulled out a couple of big folders filled with lots of paper and pulled out about a hundred pages and asked him if he testified in the trial of blah versus blah because I have the transcript of his testimony right here, and he admitted that he had. I asked if he had in fact testified in several cases, pointing to the stack of papers saying, “I have lots of transcripts here. Do I need to pull them all out?” and he reluctantly answered “yes”. He

quickly clarified that he only meant to say that he had not testified for this particular airline, not any airline. This caused the judge to squint at him. I asked if he had ever testified behalf of a pilot that fumes had caused impairment? He said he would never do that because these fumes are harmless. I asked him if his opinion would be different if both pilots had died right there in the cockpit during the fume event and he said no it wouldn't. He would want to know what they had to eat that day. More squinting from the judge.

I then went through a barrage of scientific papers that contradicted his theories: "What about this language in Freudenthal? How do you reconcile your opinion with Houtzager, or the research from Howard and Michaelis?" One by one he admitted not being familiar with them. He has research associates who do the research and then write him memos. He did offer to read them on the witness stand and comment. I told him that it wasn't my job to teach him his job.

Thanks to the banker's box idea, I was able to highlight the extent to which the studies he cited don't really say what he claims they say. I knew from experience that this particular judge is just the type of person who would paw through his box and read it for himself. His 100 page order reflects the fact that he clearly did. For example, their expert testified that he can tell what the maximum possible exposure could ever be in any fume event, citing several studies. My response was that none of papers he cited for this proposition involved measurements taken during an actual fume event. You had lots of measurements taken under normal flight conditions, a few smell events, and one with air samples taken on the tarmac. The 2011 De Nola study he cited looked at 78 samples from military aircraft. None were taken during a fume event and they actually threw out two samples because they deemed the measurements to be too high. If only life was that easy.

In my closing argument I noted that making this assertion is like declaring that you can tell what the maximum possible exposure to smoke would be in a house fire by taking a measurement of the air quality in a house that is not on fire. I also made a point of differentiating between a fume event and a smell event. This comes up in two contexts: first, underreporting of fume events by call them smell events, second by allowing them to claim that research shows no TCP in the air even during a fume event. I explained to the court that a fume event is bad enough to cause a diversion of the flight or requiring medical care. A smell event is when you are sitting next to a passenger with bad flatulence. Since he probably isn't farting out TCP, the air samples will be negative for that.

The discrediting of their witness was successful. The judge stated in his order that this expert was professionally biased (ouch) and that while he certainly was well credentialed, his opinion was riddled with flaws both big and small (ouch).

The most important preparation to effectively cross examine their experts is to read the transcripts of their prior testimony so you know what they are going to say, and look up all the research they cite so that you can demonstrate that it doesn't say what they claim it says.

6.2.3 Another Line of Attack: Fumes are Harmless

Another line of attack you should anticipate comes courtesy of the OSHA regulations that suggest that these fumes are harmless. A little humor and perhaps sarcasm is in order here. I pointed out that these regulations are based on outdated science that attempted to measure how much of this crap a hen has to drink before it falls over paralyzed. I like the comment in one of the research papers that hens are favored over rats as subjects because they fall over nicely when paralyzed.

There are several holes in the science behind these regulations. Hens are not humans, inhalation is worse than ingestion, and there is a lot of harm that can be done short of paralysis. Captain Myers is severely disabled and yet he would be a negative response on this study because he didn't fall over paralyzed.

6.2.4 This Next Attack: Are You a Toxicologist?

This next attack you should expect was beaten like a drum throughout this litigation: “Are you a toxicologist?” The cross examination of every one of our 13 expert witnesses (other than Dr. Abou Donia who is a toxicologist) started with this line of questioning, “Are you a toxicologist? Wouldn’t you agree that this case comes down to the toxicology? Wouldn’t you defer to the toxicologists? And you’re not a toxicologist, are you?” It took me several depositions before I caught on to their strategy.

By doing this, they want to neutralize everyone who is not a toxicologist so the whole case comes down to their toxicologist against whatever toxicologist you have. They think they will win that battle, especially in front of a jury. Chances are, your toxicologist is not professional witnesses like their witness will be. That matters, unfortunately. Just really knowing your stuff doesn’t make you an effective witness. You still have to be able to patiently break the science down to the grade school level for your jury while at the same nimbly dancing around the various traps and snares tossed out there by a good trial attorney. This is where the links of the chain concept comes in handy. I pointed out to the court that opposing counsel spent most of his time belittling the doctors because they are not scientists and the scientists because they are not doctors. They don’t have to be. Each link relies on the other links.

Your scientists don’t need to read thousands of pages of medical records or the maintenance records to render a persuasive opinion. Those are the other links of the chain. Their opinion centers around the scientific plausibility of harmful effects from fumes, assuming that the surrounding factual and medical links are true. The fact that their expert has read the medical record does not make their opinion stronger. Similarly, your doctors do not defer to the toxicologists, and they do not defer to the mechanics. Their opinion by necessity assumes the facts of your case. They were not on the flight deck when this happened. And, they are assuming that this causal connection is scientifically plausible. Don’t let your doctors stumble into defending and explaining the science unless they happen to really know this stuff, which is unlikely. It is better to have them stick to the concept that they are assuming the accuracy of the factual history and assuming the plausibility of the science. Remember, they are not deferring to the “toxicologists”.

At this conference we have listened to some of the brightest minds in the world, people from over two dozen different specialties and fields. According to this industry logic, virtually all of you would have to defer to the industry toxicologist. I think we would all take exception to that notion. Fortunately, the judge in our case did too. This bizarre obsession with toxicology led to the following vignette on day two of my trial. Judith Andersons was our first witness that day. Dr. Susan Michaelis, my wife Helen and several other people were sitting in the back of the courtroom. I began with the good old trial tactic called steeling their thunder. I spent the first 15 minutes of direct examination establishing that Judith was not a toxicologist. We also established that she does, however, have considerable relevant education in chemistry as well as extensive training and firsthand experience investigating fume events that make her eminently qualified as an expert. She also explained that there were many other disciplines, specialties, and degrees that would be highly useful in providing expert testimony. I was also later accused by my wife of having sarcastically mimicked opposing counsel when I asked Judith on direct, “Are you a toxicologist?”

Despite this effort to mock this whole line of questioning, opposing counsel’s very first question was, “Are you a toxicologist?” This produced an audible groan from the back of the room. Then after ten more minutes of beating this very dead horse came yet another question about her lack of toxicological training and there came another, this time, barely perceptible sound from the back of the courtroom leading opposing counsel, with trembling hand, to stop the proceedings and loudly demand that the judge clear the courtroom: “There is chortling going on back there and it’s making it impossible for me to concentrate.” All eyes then turn to the back of the room where Susan and Helen both sat in the corner looking as innocent as possible like the cat that ate the canary. No chortling here, no sirree bob.

Well, the judge said he didn’t hear anything and refused to clear the courtroom (although I suspect he did and he was probably stifling his own chortle) I resisted the temptation of observing that audience will stop chortling when you stop asking stupid questions. I will say that the judge subtly expressed his opinion on this matter when he stated in his order that he considered Judith to also be a toxicologist.

6.3 Attacks on the Third Link: Medical Causation

You should expect the other side to argue that the most harm that can ever come from a fume event is perhaps a little coughing and perhaps a little effect on the peripheral nerves but nothing that ever lasts more than a day or two and certainly nothing that effects the central nervous system. You need your scientists affirm your that these fumes cause much more than that, and your doctors to affirm that the various conditions they are treating have been caused by these fumes. I see a two step process to prove that these fumes can impair the central nervous system.

First, show how these chemicals actually affect the body. Be sure that you bring this science down to the Grade School level for your judge or jury. Second, bring in the research showing how widespread the reporting of these effects has been worldwide. The work of Dr. Michaelis in 2016 is useful here.

I used the Rain in July argument here. If the other side asserts that it can never rain in July, the fact that there is evidence that it has rained in July many times before undermines their claim. The fact that hundreds of people have had central nervous system effects undermines their claim of impossibility. However, you can't prove this point with this data alone. You need to have the scientific proof as to how this happens.

6.4 The Final Link: Your Client's Disability

This has its own set of attacks. Is your client really impaired? The basic argument is that since everyone knows that these fumes are harmless, your client's complaints are either the result of some other medical condition, or his is simply faking. You need to defend both possibilities.

First, eliminate all the other potential medical causes. They will say all these conditions are diffuse and can have other explanations. Fine. Eliminate the other explanations. The big battle will over your client's credibility. I brought in several other pilots to testify about how much my client loves flying and would never voluntarily give that up and would never fake anything. You need to do the same. You can also expect massive amounts of surveillance, so this would be a really bad time for your client to take up the unicycle. Both my client and I were followed and harassed. You should expect that and prepare your client for that.

I made sure that my character witnesses were all in uniform, as was my client. I also insisted that he be referred to as Captain Myers throughout the trial. The judge agreed, saying he had earned that, which I took to be an early good sign. We did such a good job of establishing my client's credibility that when the other side made a few half hearted attempts to malign him in their closing argument, I referred to that as throwing Mud on the Mona Lisa in my Rely Argument. Maybe it won't look quite as good, at least until it is wiped off, but it doesn't detract from the intrinsic quality of the painting.

So there you have it, *build your case, defend your castle*.

7 Closing Thoughts

Now, I'd like to close with two thoughts.

My first thought, why are we all really here at this conference? Yes, we have accomplished all of our stated goals for this conference. But what is the real overriding goal. We want safer air to breathe on airplanes for crew and passengers. *The more we can understand this issue and the science, the more we can effectively advocate for and accomplish changes that will bring us that clean air.*

My second thought is that I see three ways that these necessary changes can happen:

1. Voluntary changes by the airlines. Sometimes with corporations this really does happen. It isn't always a battle between good and evil. Unfortunately, there are economic factors working against that option. These are expen-

sive changes at a time when Covid has decimated the airline industry. At this point it is still cheaper for them to crush each case that comes along rather than to fix the planes.

2. Governments can regulate and legislate rules and laws to effect these changes. However, that is a slow process. Regulatory agencies can be unresponsive and often are more concerned about the wellbeing of the companies than their employees. Legislative changes have to overcome powerful lobbies. Nevertheless, there is increasing pressure for change and there is some cause for hope. Eventually.
3. This leaves the courts and us trial lawyers. We can force changes, and we have done it before. We are the tip of the sword. This one loss to me won't change the airline industry, but the next twenty losses that follow will. *At some point the financial threat of judgments will outweigh the cost of change*. The good old bottom line.

Frankly, I don't care whether they make the changes for the right reasons or the wrong ones. Just make the dang changes. The time is ripe. Think of big tobacco. When I was a kid it was an open question as to whether or not tobacco was harmful. The tobacco institute had some very well credentialed scientists who backed them up. Powerful forces blocked legislation. Smoking was even allowed on planes, which seems crazy now. It's like a public swimming pool that has a peeing section and a non peeing section. Now, it's taken for granted that tobacco in all forms is bad for you. It even says so on the label now. There no longer is a credible argument to the contrary, thanks in part to a flood of successful litigation. However, to start that flood someone had to win that first case.

That's where we are now with cabin air safety. We are right on the cusp of change. We have won that first case. *I have given you the roadmap of how to win the next one*. Soon, the argument that these fumes are harmless will be laughed out of the room like so much tobacco smoke. But it will take winning more cases like mine. I sincerely hope that my case and this talk can help that cause. At some point we will make it more costly for the industry not to make the necessary changes.

But you have to win your cases. There is too much at stake: both the financial well-being of your client, and the health and safety of everyone who flies. You have to care more than they do. You have to leave nothing to chance. You have to prepare your witnesses for the predictable cross examination. Do not underestimate the other side. Know their case better than they even do. Obtain and read transcripts from other trials so you know what their experts will say in advance. Know the research so well that you can rattle it off while you cross examine their witnesses. And above all, make your case and your experts understandable to your judge or jury. You are not trying to win a High School debate. Persuade your judge and jury. And just win the damn case. We are the tip of the sword. And may your edge ever be sharp.

This is Glen Lasken, coming to you from the snowy mountains of Sisters, Oregon.



We create chemistry

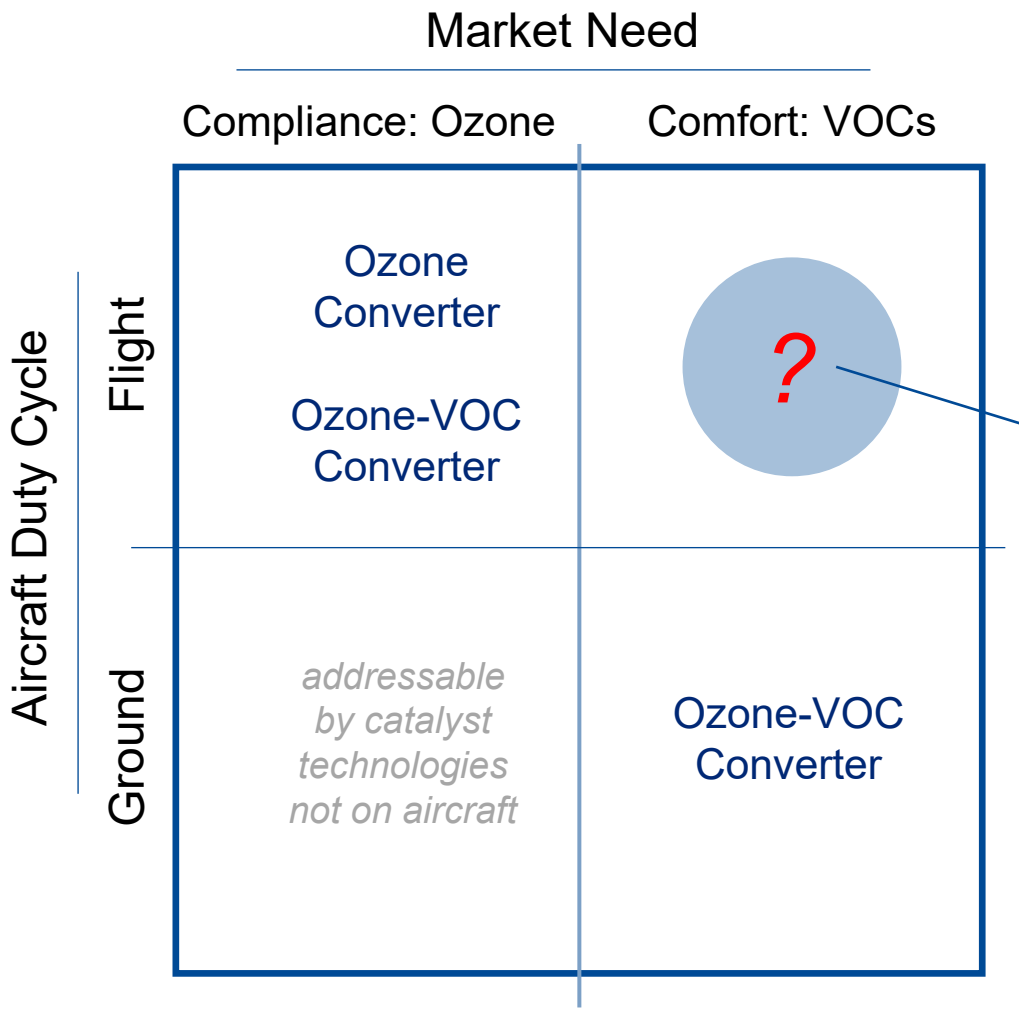
Victor Leung:

Ozone-VOC Converters: Enhance Your Comfort

Aircraft Cabin Air Conference

Online, March 18, 2021

AN EMERGING MARKET NEED: VOC MITIGATION OPTIONS IN FLIGHT



What options are available among current converter technologies to mitigate VOCs in flight?

Enhance your comfort:

- Mitigate cabin odors
- Mitigate exposure to VOCs

BASF
We create chemistry

Today's outline:



- **Who we are – BASF**
- What we've learned about VOCs in the cabin
- How our converters deliver sustainable performance

BASF Overview

- **We create chemistry for a sustainable future.**



- We are one of the world's leading companies in reporting on climate protection and sustainable water management
- Sales (2020): €59.1B
- Employees (2020): 110,302
- 6 Verbund sites and 355 other production sites

CLEAN AIR IS A STRATEGIC TOPIC AT BASF FOR ITS SUSTAINABILITY

BUSINESS SEGMENTS	BUSINESS DIVISIONS	STRATEGIC BUSINESS UNITS
Surface Technologies	Catalysts	Process Catalysts
	Coatings	
Industrial Solutions		
Nutrition & Care		
Agricultural Solutions		
Materials		
Chemicals		

Clean Air Solutions

Clean Air Solutions is committed to providing innovative solutions to the most complex emissions control problems for stationary, aerospace and indoor air.



Catalysts and adsorbents…

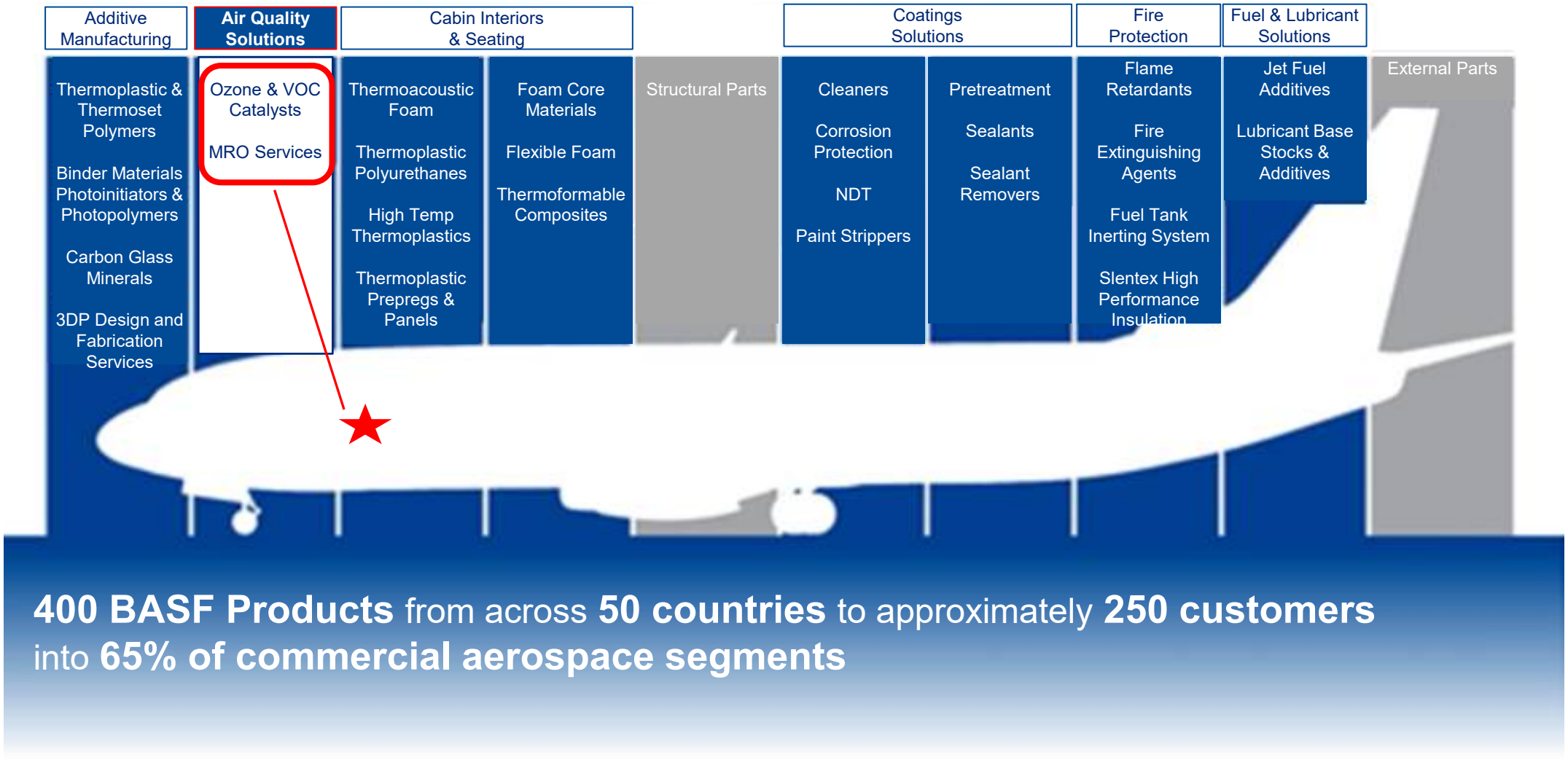
Mobile Emissions Catalysts

Battery Materials

Precious & Base Metal Services

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BASF PORTFOLIO OF AEROSPACE MATERIALS…



400 BASF Products from across **50 countries** to approximately **250 customers** into **65% of commercial aerospace segments**

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If you've flown over an ocean within the last 30 years…

…then you've likely breathed air that has passed though a BASF Ozone or Ozone-VOC converter



A330/A340

Mandatory on wide-body aircraft

Optional on single-aisle aircraft



EJET E2

Standard equipment on latest regional jets



G650X

Enhances premium flight experience on business jets



A400M

Used on certain military aircraft to improve pilot performance

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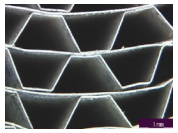
OZONE AND OZONE-VOC CONVERTERS ARE EFFECTIVE MEANS TO ATTAIN COMPLIANCE WITH CABIN AIR OZONE STANDARDS



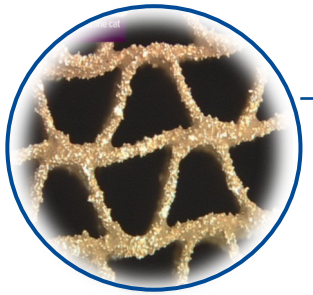
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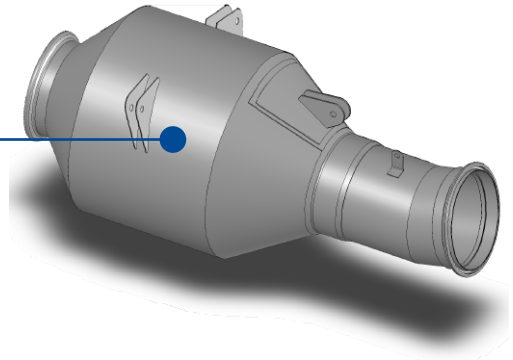
WASHCOAT



SUBSTRATE



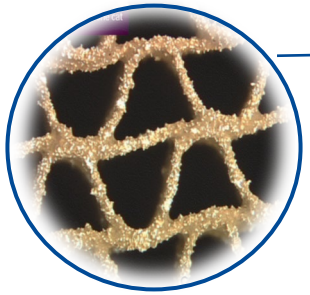
OZONE CATALYST



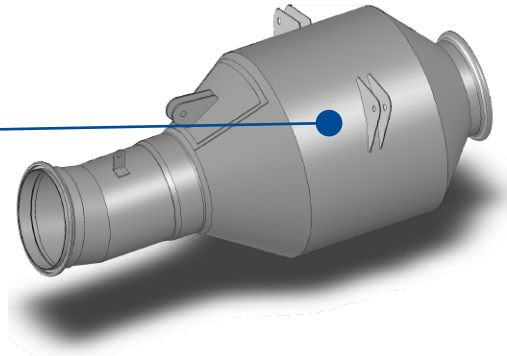
OZONE CONVERTER

Installed in Environmental Control System





OZONE-VOC CATALYST



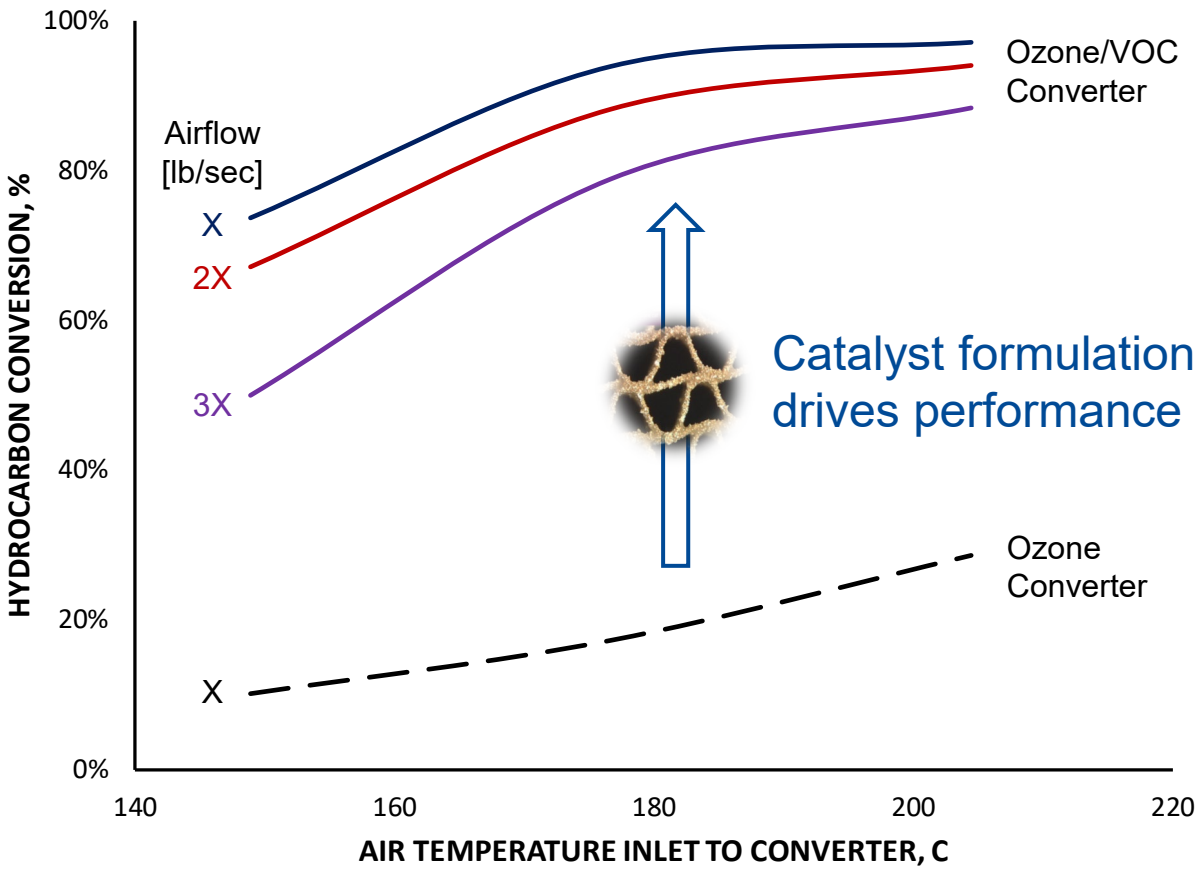
OZONE-VOC CONVERTER

SAME HOUSING ALLOWS UPGRADE WITHOUT DISRUPTION

- Custom designed and built for ozone conversion efficiencies as high as 97%+
- Sustainable solution:
  Catalyst is not consumed in the reaction – activity may be lost due to contamination

BASF
We create chemistry

OZONE-VOC CONVERTERS HAVE BEEN MITIGATING FUEL-DERIVED GROUND ODORS IN THE CABIN FOR 15+ YEARS



You are here....

80%+ less fuel-derived ground odors in the cabin if your plane has an ozone-VOC converter installed



BTEX = Mixture of benzene, toluene, ethyl benzene, and xylene
Converter initial performance shown – 0 FH

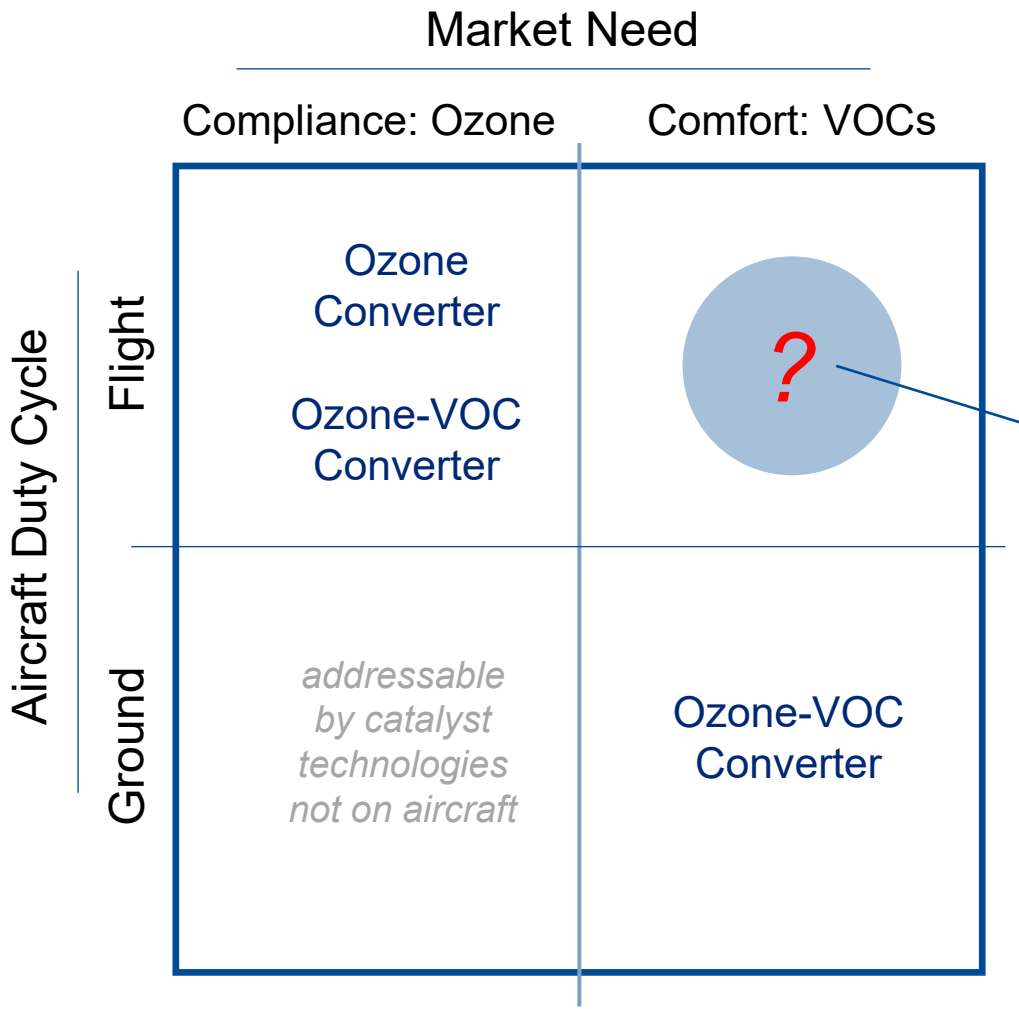
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TODAY'S OUTLINE:



- ✓ WHO WE ARE – BASF
- **WHAT WE'VE LEARNED ABOUT VOCS IN THE CABIN**
- HOW OUR CONVERTERS DELIVER SUSTAINABLE PERFORMANCE

AN EMERGING MARKET NEED: VOC MITIGATION OPTIONS IN FLIGHT



What options are available among current converter technologies to mitigate VOCs in flight?

Enhance your comfort:

- Mitigate cabin odors
- Mitigate exposure to VOCs

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CHEMICAL REACTIONS MAY TAKE PLACE IN THE BLEED AIR SYSTEM FOR EXAMPLE: HYDROLYSIS

- Polyol Esters are the main component of aviation engine oils

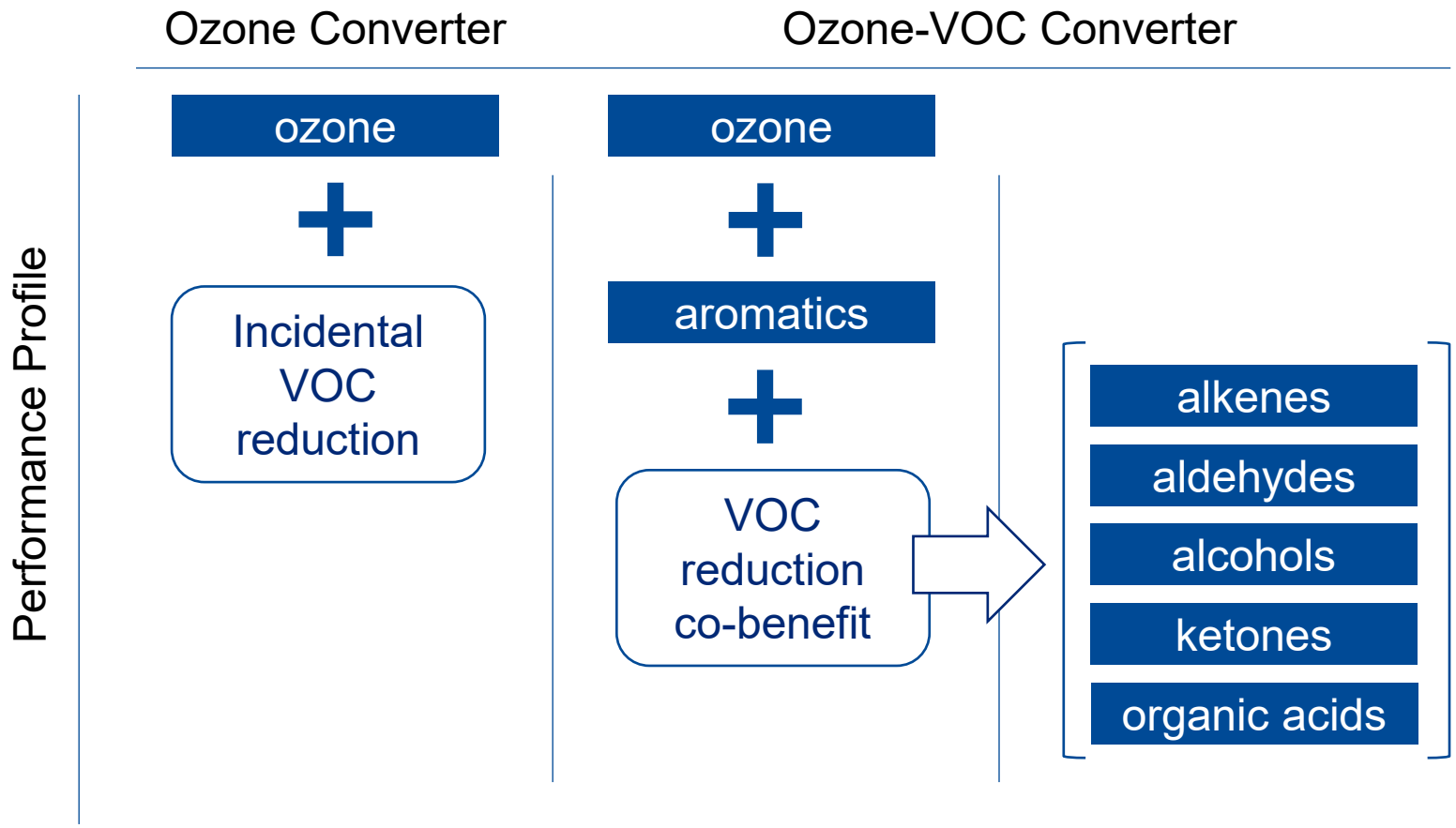
Polyols + Organic Acids $\underset{\text{Hydrolysis}}{\overset{\text{Esterification}}{\rightleftharpoons}}$ Polyol Ester + Water

- This is a reversible reaction
  - Some of the Polyol Ester, in the presence of water, will revert to its constituent polyols and organic acids
- Some of these acids have particularly noticeable odor
  - i.e., valeric acid – rancidity … “dirty socks smell”



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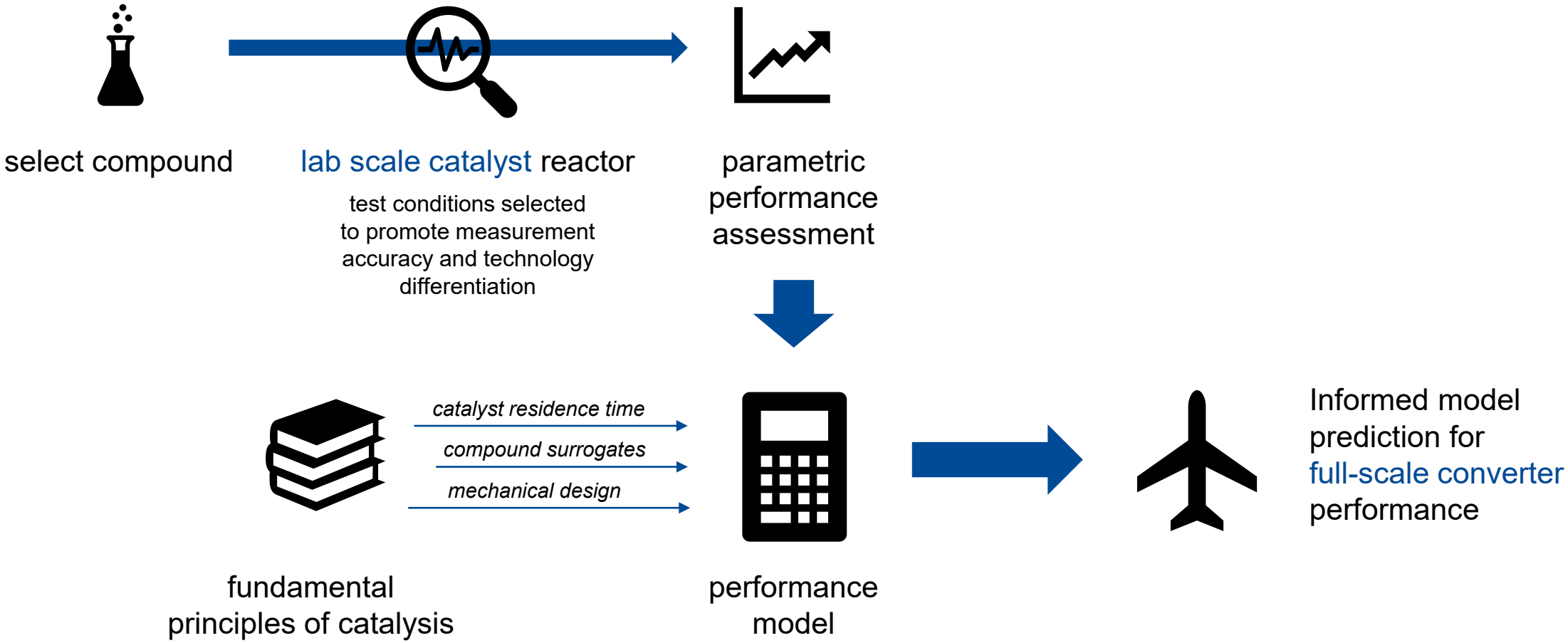
BASF EXPANDED THE SCOPE OF THE OZONE-VOC CONVERTER: WHAT PERFORMANCE CAN IT DELIVER FOR OTHER VOCS



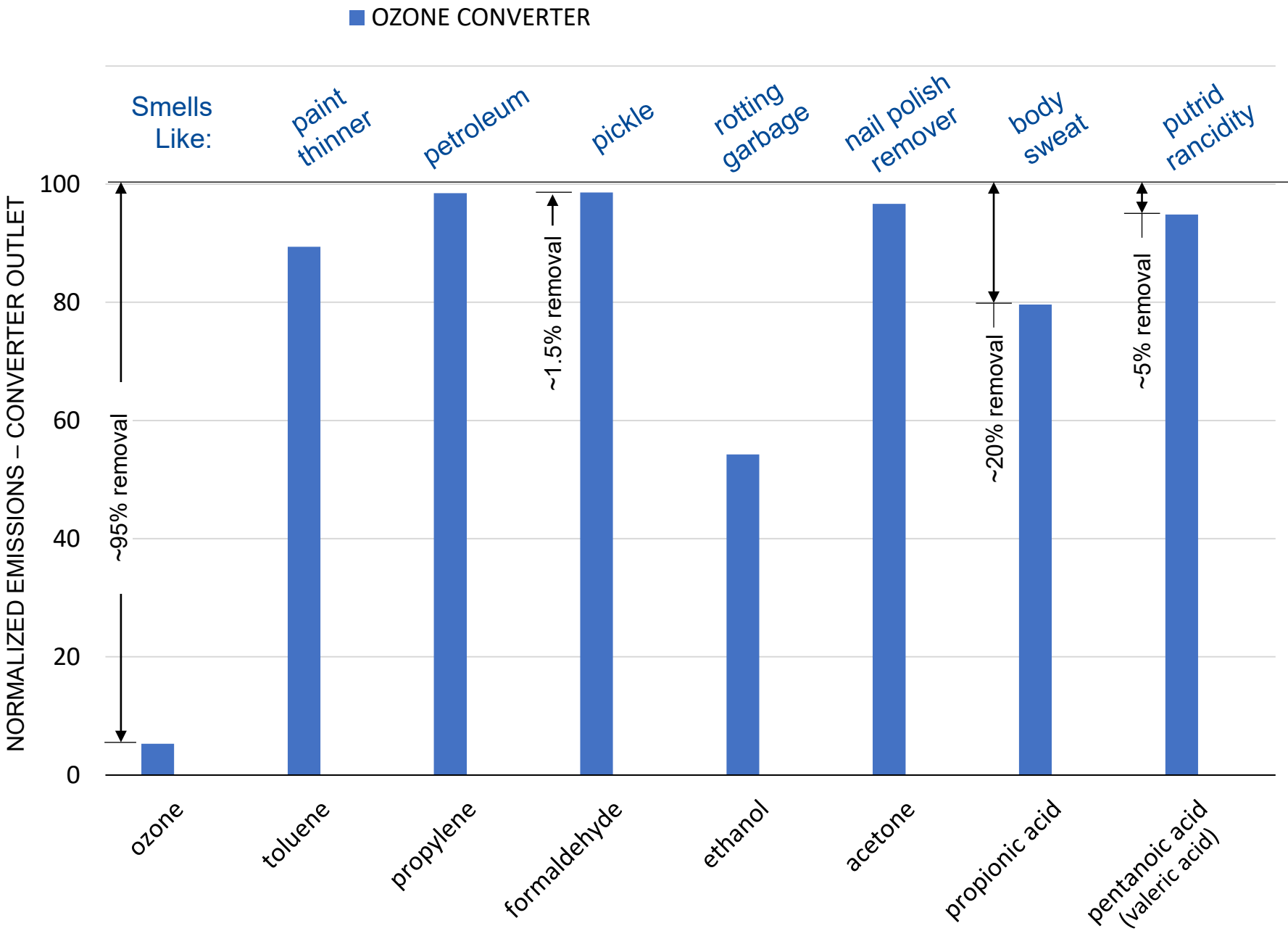
- Representative compounds selected from each chemical class
- Passed as single compound streams through ozone-VOC catalyst in lab environment

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BASF ASSESSMENT METHODOLOGY:
FROM LAB SCALE TESTS TO FULL SCALE MODELED RESULTS



BASF
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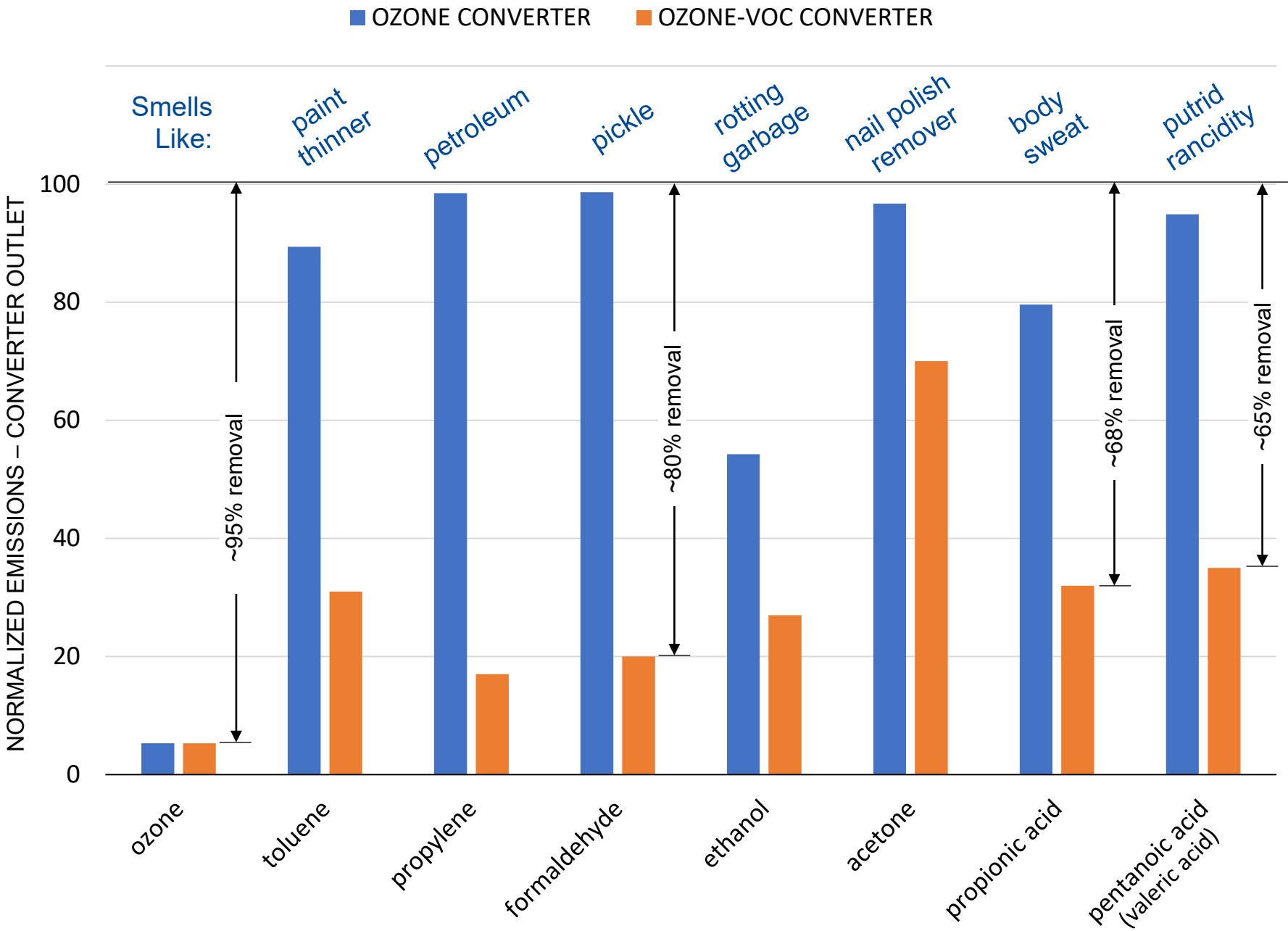


Ozone converters are designed to reduce ozone concentration

Incidental benefits for the moderate conversion of select VOCs are available

Note: Single compound testing. Modeled performance for full-scale converter in commercial application.

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Ozone-VOC converters are designed to reduce ozone and VOC concentrations – mitigating odors in the cabin

~10X improvement in removal efficiency for the nastiest odors in bleed air such as pentanoic acid (valeric acid)

Note: Single compound testing. Modeled performance for full-scale converter in commercial application.

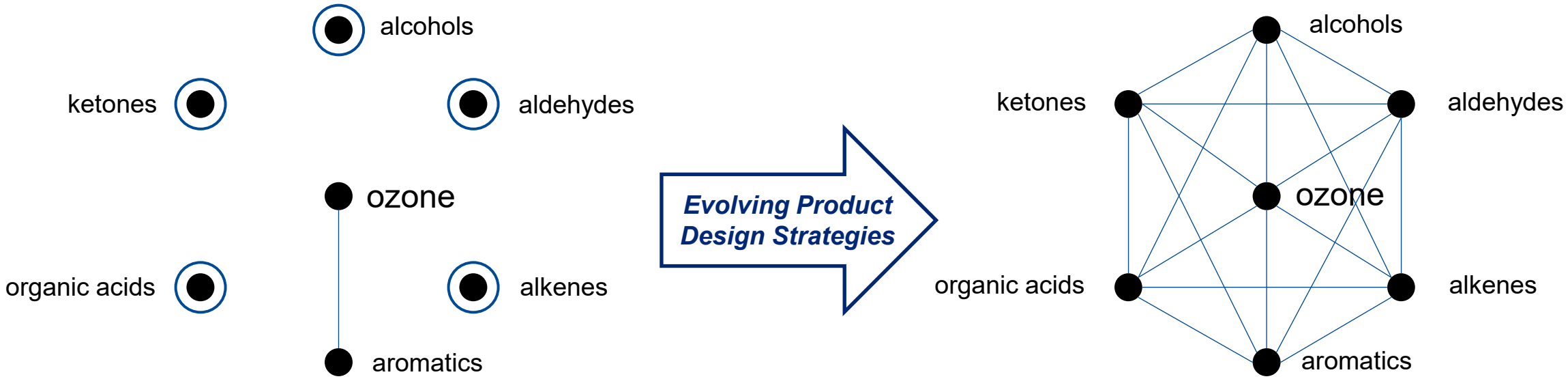
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OZONE-VOC CONVERTER OFFERS ENHANCED COMFORT A "NOW" OPTION TO MEET THE CHEMISTRY CHALLENGE OF VOC ODOR

- Ozone-VOC converter upgrade:
  - Retain existing ozone conversion performance
  - Significantly mitigate cabin odors from sources external and internal to the aircraft
  - Significantly improve the cabin experience
- Ozone-VOC converter technology
  - Proven with 15+ years of commercial flight
  - Robust "now" option to meet evolving challenges in cabin air
- BASF continues its aircraft converter catalyst technology evolution to respond to market needs

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BASF CONTINUES TO EVOLVE AIRCRAFT CONVERTER CATALYST TECHNOLOGY TO RESPOND TO MORE COMPLEX CHALLENGES IN THE CABIN AIR



Single compound evaluations to assess value of current Ozone-VOC catalyst technology

Multi-compound optimization to drive innovation to next-gen Ozone-VOC catalyst technology

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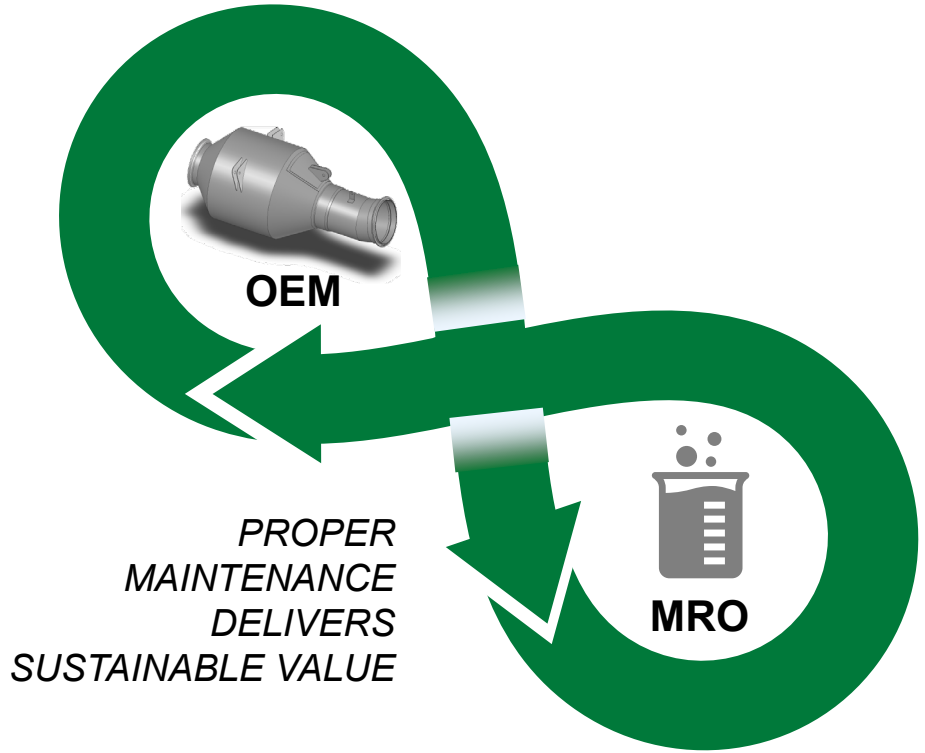
TODAY'S OUTLINE:



- ✓ WHO WE ARE – BASF
- ✓ WHAT WE'VE LEARNED ABOUT VOCS IN THE CABIN
- **HOW OUR CONVERTERS DELIVER SUSTAINABLE PERFORMANCE**

INSTALLED CONVERTERS ARE ONLY PART OF THE EQUATION … PROPER MAINTENANCE IS ESSENTIAL

- Ozone and Ozone-VOC converters are rotables and must be maintained properly to ensure effective performance and regulatory compliance with cabin air standards
- Poorly or improperly maintained converters do not guarantee continued performance
- As the OEM and MRO, BASF has the breadth and depth of knowledge to maintain the catalyst performance in a manner that leverages the original design and thereby extends converter useful life



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Robust OEM Design + BASF MRO Service
A sustainable solution in action

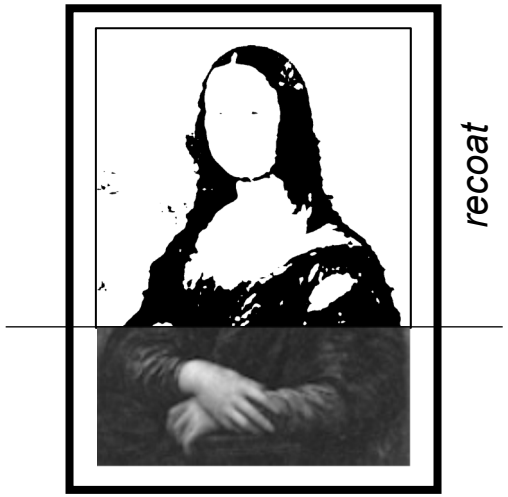


Ozone Converter P/N 20224-1 S/N 0180

- In service since 1987 (34 years)
- Exclusive service history with BASF MRO
- Robust OEM design + BASF MRO Service
  - ✓ Ensures comfort and compliance over design life
  - ✓ Provides value to the operator
  - ✓ Sustainability: fully functioning product remains in the value chain

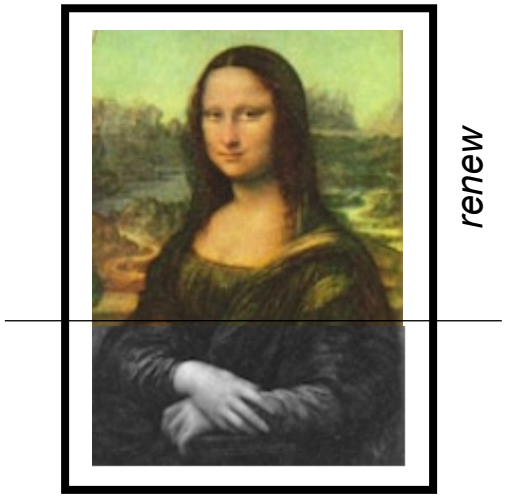
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COMPARISON OF ~~CONVERTER~~ CATALYST SERVICE METHODS



STRIP & **RECOAT**

Not quite like the original, but close enough?



RENEW BY DEEP PORE CLEANING

BASF MRO

Preserves catalyst pore structure for enduring value and performance



OVERCOAT WITH DIFFERENT ACTIVE COMPONENT & WASHCOAT

Paints a different picture but it still fits the original's frame

…other service methods (water wash, compressed air. etc.) do not remove embedded contaminants and may damage the catalyst core and compromise performance and service life…

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BASF HAS UPDATED ACMMS TO PROVIDE FURTHER GUIDANCE ON PROPER OZONE AND OZONE-VOC CONVERTER MAINTENANCE

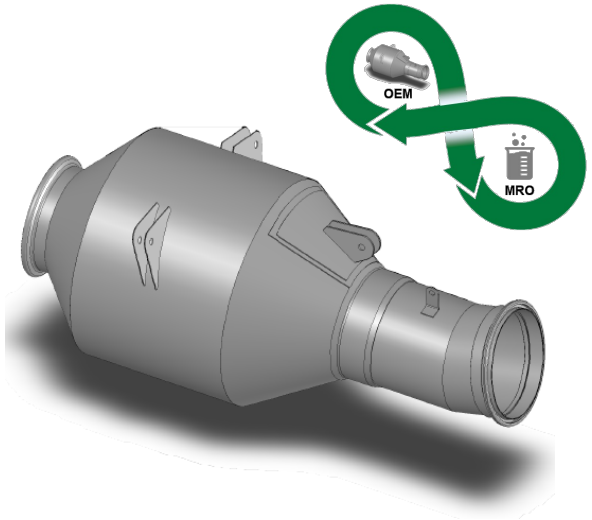
- BASF surveyed the MRO landscape and found:
  - Non-OEM and Airframer approved service methods
  - No testing standard to evaluate and compare performance
- Updated ACMMs give guidance on OEM approved service methods and test standards to ensure consistent performance evaluation
- BASF has revised and issued updated ACMMs
  - A320 Ozone and Ozone-VOC Converters
  - A330/340 Ozone and Ozone-VOC Converters
- Other platforms will be revised on an ongoing basis


BASF
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BASF CORPORATION
9800 KELLNER ROAD
HUNTSVILLE, AL 35824
USA
Tel: +1 732 205 6078
aircraft.cleanair@basf.com
1KGC9
ABBREVIATED COMPONENT MAINTENANCE MANUAL
Deoxo™ Ozone Converter
ACMM 21-11-04
Issue 11 – Apr 06/20
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The statements made herein do not constitute an offer. They are based on the mentioned assumptions and are expressed in good faith. Where the supporting grounds for these statements are not shown, BASF Corporation will be pleased to explain the basis thereof.
SOP 00625
Issue 7
Apr 06/20
EAR ECCN 9E991. This technical information is subject to Export Administration Regulations. Dissemination (export or re-export/retransfer of the data) contrary to U.S. Export Law(s) is prohibited.
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CONFIDENTIAL
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PROPERLY SERVICED, CONVERTERS ARE AN INVESTMENT IN CLEAN AIR THAT RETAINS VALUE OVER THE LIFE OF THE AIRCRAFT





BASF MRO Services

- Performance test
- Chemical wash to remove contaminants and renew pore structure of catalyst
- Converter recore to replace catalyst core within existing structure
- A sustainable solution of lasting value

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THE AIRCRAFT IS YOUR WORKSPACE AND YOU DESERVE QUALITY CABIN AIR







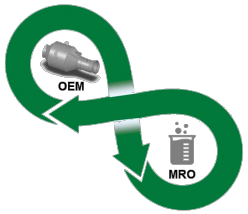
BASF
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BASF Clean Air has responded to market needs and innovated solutions in aviation cabin air for 38 years



15+ years of commercial service: BASF Ozone-VOC converters



2

2 Keys to Converter Sustainability:

Robust OEM Design & BASF MRO Service

0

Days to wait for you to enhance your comfort in the aircraft cabin

BASF thanks you for the opportunity to discuss these issues today…

ultimately, each and every one of you is our end customer

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BASF

We create chemistry

International Aircraft Cabin Air Conference 2021
Online, 15 – 18 March 2021

Zoe Littlepage



Matt Leckman



Rainey Booth

Zoe Littlepage

Littlepage Booth Leckman

IN THE CIRCUIT COURT OF COOK COUNTY ILLINOIS
COUNTY DEPARTMENT, LAW DIVISION

VANESSA WOODS, a single woman;
FAYE OSKARDOTTIR, a single woman;
DARLENE RAMIREZ, a single woman;
and KAREN NEBEN and NATHAN NEBEN, husband and wife,

Plaintiffs,

v.

THE BOEING COMPANY,

Defendant.

2015L006324
CALENDAR/ROOM R
TIME 00:00
PI Other

NO. _____

Plaintiffs

2015 JUN 22 AM 8:42

COMPLAINT

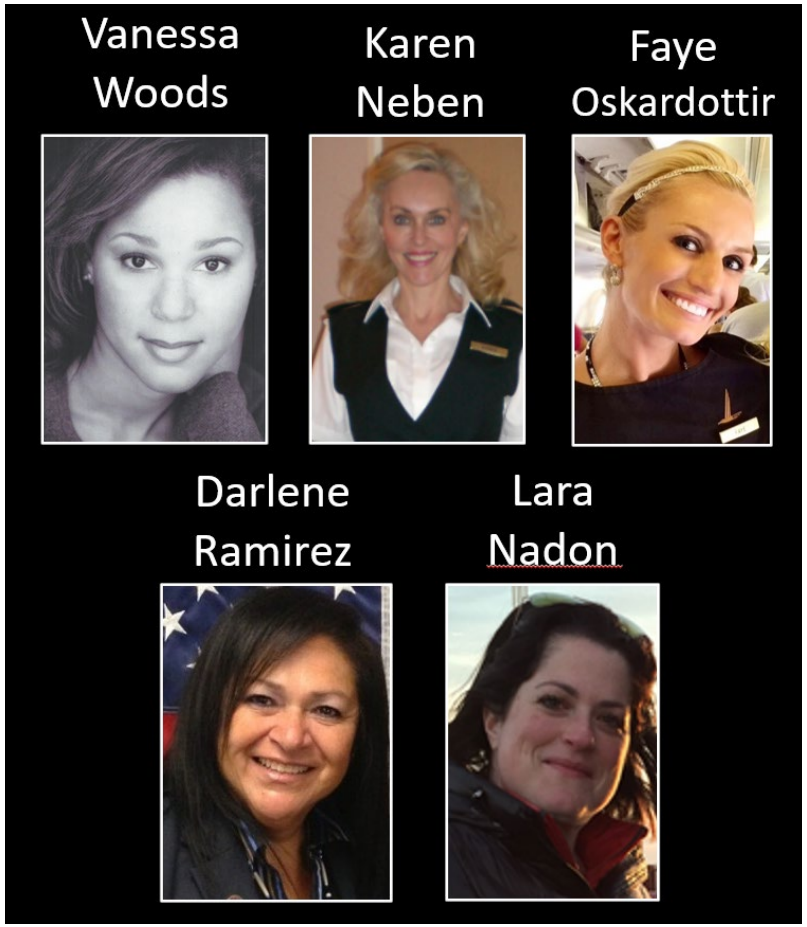
Plaintiffs VANESSA WOODS ("Ms. Woods"), FAYE OSKARDOTTIR ("Ms. Oskardottir"), DARLENE RAMIREZ ("Ms. Ramirez"), KAREN NEBEN ("Mrs. Neben") and NATHAN NEBEN ("Mr. Neben"), by and through their attorneys, POWER ROGERS & SMITH, P.C., FRIEDMAN RUBIN, LITTLEPAGE BOOTH, and BRODKOWITZ LAW, file this Complaint against the above-named Defendant (hereinafter referred to as "Boeing") and state as follows:

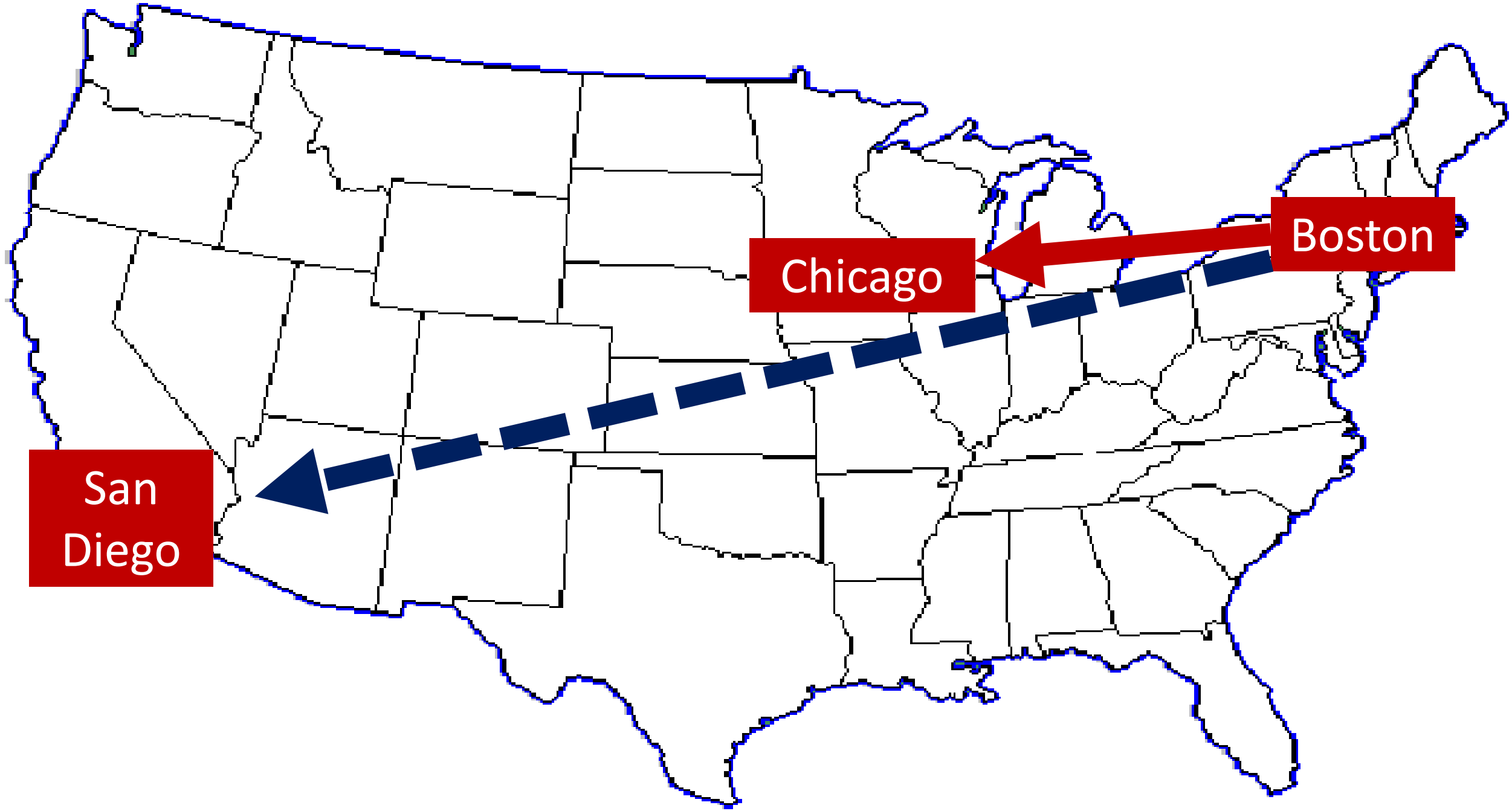
PARTIES

1. Ms. Woods is a citizen of the United States of America, domiciled in Newport Beach, California.

2. Ms. Oskardottir is a citizen of the United States of America, domiciled in Rancho Santa Margarita, California.






Boston
Chicago
San Diego

IN THE CIRCUIT COURT OF COOK COUNTY ILLINOIS
COUNTY DEPARTMENT, LA

VANESSA WOODS, a single woman;)
FAYE OSKARDOTTIR, a single woman;)
DARLENE RAMIREZ, a single woman;)
and KAREN NEBEN and NATHAN)
NEBEN, husband and wife,)
)
Plaintiffs,) NO. _
)
v.)
)
THE BOEING COMPANY,) *Plaint*
)
Defendant.)
_____)

COMPLAINT

Plaintiffs VANESSA WOODS ("Ms. Woods"), FA
Oskardottir"), DARLENE RAMIREZ ("Ms. Ramirez"), K
NATHAN NEBEN ("Mr. Neben"), by and through their at
SMITH, P.C., FRIEDMAN RUBIN, LITTLEPAGE BOO
this Complaint against the above-named Defendant (herein
state as follows:

PARTIES

1. Ms. Woods is a citizen of the United States
Beach, California.

2. Ms. Oskardottir is a citizen of the United St
Santa Margarita, California.

VANESSA WOODS, a single woman;)
FAYE OSKARDOTTIR, a single woman;)
DARLENE RAMIREZ, a single woman;)
and KAREN NEBEN and NATHAN)
NEBEN, husband and wife,)
)
Plaintiffs,)
)
v.)
)
THE BOEING COMPANY,)
)
Defendant.)
_____)

IN THE CIRCUIT COURT OF COOK COUNTY ILLINOIS
COUNTY DEPARTMENT, LAW DIVISION

VANESSA WOODS, a single woman;)
FAYE OSKARDOTTIR, a single woman;)
DARLENE RAMIREZ, a single woman;)
and KAREN NEBEN and NATHAN)
NEBEN, husband and wife,)
)

2015L006324
CALENDAR/ROOM R
TIME 00:00
PI Other

IN THE CIRCUIT COURT OF COOK COUNTY ILLINOIS
COUNTY DEPARTMENT, LAW DIVISION

VANESSA WOODS, a single woman;)
FAYE OSKARDOTTIR, a single woman;)
DARLENE RAMIREZ, a single woman;)
and KAREN NEBEN and NATHAN)
NEBEN, husband and wife,)
)

2015L006324
CALENDAR/ROOM R
TIME 00:00
PI Other

1. Ms. Woods is a citizen of the United States of America,.domiciled in Newport Beach, California.

2. Ms. Oskardottir is a citizen of the United States of America, domiciled in Rancho Santa Margarita, California.

Boeing Headquarters:
Chicago, IL



Our claims

What SHOULD Boeing have done:

What SHOULD Boeing have done:

Installed Converters / Filters

What SHOULD Boeing have done:

Installed Converters / Filters

Installed Sensors

Documents

Woods v. Boeing

Boeing documents reviewed:

1.1 million pages


recall

PLAINTIFFS' MOTION FOR REMOVAL OF BOEING'S "CONFIDENTIALITY" DESIGNATION AS TO 285 IDENTIFIED DOCUMENTS, PURSUANT TO SECTION 5.1 OF THE PROTECTIVE ORDER

under seal. This is a totally unnecessary burden for the Court and the Plaintiffs. ***Sixth***, permitting Boeing to hide the important and startling safety issues uncovered in this litigation is against public policy and Illinois law. "Throughout our history, the open courtroom has been a fundamental feature of the American judicial system" *Brown & Williamson Tobacco Corp. v.*

FILED
3/25/2019 5:25 PM
DOROTHY BROWN
CIRCUIT CLERK
COOK COUNTY, IL
2015L006324

THE BOEING COMPANY,

Defendant.

PLAINTIFFS' MOTION FOR REMOVAL OF

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Moreover,

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deposition *transcript* portions, where these specific documents are discussed in detail, as confidential—as it was required to do under Section 3.6 of the Order—and notwithstanding it has provided no rationale for the claimed "confidentiality" of any of the documents in question.

1 Ex. 1: Chart of 285 documents at issue

PLAINTIFFS' MOTION FOR REMOVAL OF BOEING'S "CONFIDENTIALITY" DESIGNATION AS TO 285 IDENTIFIED DOCUMENTS, PURSUANT TO SECTION 5.1 OF THE PROTECTIVE ORDER



FILED
3/25/2019 5:25 PM
OTHY BROWN
UIT CLERK
K COUNTY, IL
L006324

PLAINTIFFS' MOTION FOR REMOVAL OF BOEING'S "CONFIDENTIALITY" DESIGNATION AS TO 285 IDENTIFIED DOCUMENTS, PURSUANT TO SECTION 5.1 OF THE PROTECTIVE ORDER

In addition to Boeing's unending parade of newly requested depositions and the ever-shifting schedule for them (detailed in Plaintiffs' last discovery motion), Boeing is now weaponizing the Protective Order (hereinafter, "the Order") in this matter to unfairly deny Plaintiffs their right to easily prepare for trial and create trial worthy evidence at Boeing's "double" depositions (where discovery depositions are followed by evidence depositions on the same day). This motion involves 285 documents, produced by Boeing in discovery and later used by Plaintiffs' counsel during the depositions of various Boeing employees.[1] Despite Plaintiffs' objections, Boeing continues to claim these documents are "confidential." Moreover, Boeing refuses to remove the confidential classifications even though it never designated the deposition *transcript* portions, where these specific documents are discussed in detail, as confidential—as it was required to do under Section 3.6 of the Order—and notwithstanding it has provided no rationale for the claimed "confidentiality" of any of the documents in question.

[1] Ex. 1: Chart of 285 documents at issue.

Depositions

Woods v. Boeing

Boeing documents reviewed: **1.1 million**

Depositions: **71**



BOEING

Air Quality Team

Richard Johnson



David Space



IN THE CIRCUIT COURT OF COOK COUNTY, ILLINOIS

COUNTY DEPARTMENT, LAW DIVISION

No. 2018 L 8347

RONALD WEILAND and

MARTHA WEILAND,

Plaintiffs,

v.

THE BOEING COMPANY,

Defendant.

Deposition of

DAVID SPACE, as a Designee of

THE BOEING COMPANY

Tuesday, June 16, 2020

9:10 a.m. (PDT)

Court Stenographer:

Myrina A. Kleinschmidt

Registered Merit Reporter

Certified Realtime Reporter

IN THE CIRCUIT COURT OF COOK COUNTY, ILLINOIS

COUNTY DEPARTMENT, LAW DIVISION

VANESSA WOODS, a single woman;)
FAYE OSKARDOTTIR, a single woman;)
DARLENE RAMIREZ, a single woman;) Hon. Christopher E. Lawler
and KAREN NEBEN and NATHAN NEBEN,)
husband and wife,) Calendar R
) Consolidated with:
Plaintiffs,) 2016 L 3846
)
vs.)
)
THE BOEING COMPANY,)
)
Defendant.)

- - -

DECEMBER 14, 2018

- - -

Oral sworn deposition of THE BOEING COMPANY through its corporate representative DAVID R. SPACE, held at PERKINS COIE Third Avenue, Suite 4900, Seattle, Washington, before Mark Hovila, CCR, CM, on the above date, commencing at a.m., there being present:

GOLKOW LITIGATION SERVICES

877.370.3377 ph | 917.591.5672 fax

deps@golkow.com

IN THE CIRCUIT COURT OF COOK COUNTY, ILLINOIS

COUNTY DEPARTMENT, LAW DIVISION

VANESSA WOODS, a single woman;)
FAYE OSKARDOTTIR, a single)
DARLENE RAMIREZ, a)
and KAREN NEBEN) No. 2015 L 006324
husband and) Calendar R
) Hon. Christopher E. Lawler
Plaintiffs,) Consolidated with:
) 2016 L 3846
COMPANY,)
)
Defendant.)

DEPOSITION OF DAVID R. SPACE

November 1, 2019

Seattle, Washington

IN THE CIRCUIT COURT OF COOK COUNTY, ILLINOIS

COUNTY DEPARTMENT, LAW DIVISION

VANESSA WOODS, a
FAYE OSKARDOTTIR
DARLENE RAMIREZ,
and KAREN NEBEN
husband and wife

Pl

vs.

THE BOEING COMPA

De

Ora
DAVID R.
Third Av
before M
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present:

G
877.3

David Space

Head of Boeing's Air Quality Team



David Space deposition on 12/11/18

p. 86-87

20 Q **So has anybody captured an upset event real-time in**
21 flight, not simulated, not on a test bed, that you
22 know of?
23 A Like I said, they're very difficult and far and in
24 between.
25 Q So they have or they haven't?
1 A **They have not, no**.

BOEING

David Space

Head of Boeing's Air Quality Team



Deposition of David Space, 11/1/19 at p. 56

Q. ...it would not be unusual to expect 4.4 fume events a day tracked back to oil or hydraulic fluid, right?

A Right.

Air Quality Team





George Bates



From: Bates, George
To: Imada, Brian T; Hamamoto, Eileen E; DeJager, Loukusa, Steven M; Johnson, Richard A
CC:
Sent: 10/26/2007 3:10:35 PM
Subject: RE: Toxicity??

The 767 / GE CF6-80A and 747 / GE CF6-80E airplane and engine combinations are better than Rolls Royce as far as frequency, but it still happens. The thing to note is the wide body events are no where as severe or dense as the 757 has experienced. The common theme is these are mostly old engines more than 15 years old. While SACO has informally discussed with me the widebody events, the thing I took away from the FAA/SACO discussion is the New England FAA is not interested in following up or supporting SACO on these events that are generally resulting from out of production engines. Bottom line is I think we are looking for a tombstone before anyone with any horsepower is going to take interest.



From:
To:
CC:
Sent:
Subject:

No, I have
Hydraulic
filters ha
what Brian

I will add
us. For the 747-8, John Klym was the most recent to try to get the Propulsion folks to step up to owning their system by-products. All he got was the run around like I got in 2000 for the 767-400. Pratt & Whitney has some guarantees in their spec but GE and Rolls Royce engine specs do n
Engi

Give
Fan
have
and
made
sign
visi
over
evac
Sheet
compl

The
Rolls
event
are
wide
not i
from
anyon

Thank
Georg
Boeing Environmental Controls
Wide Body Lav/Galley Vent, Cargo Cond / 767 Air Dist Cert
Office Phone: (425) 294-6996
Fax: (425) 294-7434
M/S 0T-29

-----Original Message-----
From: Imada, Brian T
Sent: Friday, October 26, 2007 10:54 AM
To: Hamamoto, Eileen E; DeJager, Alan; Fay, Dennis M; Bates, George
Cc: Loukusa, Steven M; Johnson, Richard A
Subject: RE: Toxicity??

We specifically limited the coverage for failures & malfunctions to our equipment & systems. It didn't look like we had any wording for normal operation -- this should be added to limit your approval, unless you want to be approving the high pressure equipment & ducting. Like I said previously, this appears to be a hole in compliance coverage.

For Section 25.831(c) in the 767-400ER certification plan included this statement:

"Failures or malfunctions of air distribution systems or components will be analyzed by FHA (Section 3.0, Table 2). Further analyses (FMEA, etc) will be conducted as necessary to show

Deposition of George Bates, 9/21/18

p. 251

Q. And it talks about that David Space has been pushing for cabin environment monitoring as part of his air quality initiative. Correct?

A. Yes.

p. 253

Q. And this instrument would be some sort of a sensor?

A. A sensor, yes.

p. 254-256

Q. And you express in this email that the biggest impeding factor is the legal issues, right? That's what you say?

A. Okay, got it.

Q. ... Your concern was someone says, "I got sick on your plane." Correct?

A. Yes.

Q. And they say: "I want to see the sensor data. I want to see what I was exposed to."

A. Yes.

Q. And then you'd have to turn over that sensor data?

A. Yes.

George Bates
Senior Engineer

BOEING





George Bates
Senior Engineer

p. 256

Q. So as I sit here today, my clients would know exactly what they were exposed to if you had put a sensor on your planes. That was your concern, right?

A. Potentially, yes.

Q. And you thought that could open a big can of worms.

A. That is one consideration.

Q. And your concern was, is that people who were exposed to contaminants would have actual data about what they were exposed to that they could use in a court of law against Boeing. That was your concern, right?

A. That is one concern.

BOEING



Air Quality Team















George McEachen

Boeing's Designated Corporate Expert



Deposition of George McEachen (11/4/19)

p. 62-63

Q And I think I understand your expert opinion, which is that even looking only at lab results or normal flight operations, we see studies where neurotoxins are found in the cabin air, correct?

A Yes.



Dr. Dennis Stumpp

Occupational Medicine Physician for Boeing



Dr. Dennis Stumpp

Occupational Medicine Physician
for Boeing

Deposition of Dr. Dennis Stumpp (4/11/19)
p. 54-55

Q. Do you believe that someone can get hurt from breathing in contaminated air in an aircraft while in flight.

A. Certainly.

Q. You believe, as a general proposition, that someone can get hurt from a toxic exposure to contaminated air while in flight.

A. Yes.

FILED
11/27/2019 1:10 PM
DOROTHY BROWN
CIRCUIT CLERK
COOK COUNTY, IL
2015L006324

IN THE CIRCUIT COURT OF COOK COUNTY,
ILLINOIS COUNTY DEPARTMENT – LAW DIVISION

VANESSA WOODS, et al.

Plaintiffs,

v.

THE BOEING COMPANY,

Defendant.

No. 15 L 006324
Consolidated with No. 16 L 3846

PLAINTIFFS' MOTION FOR LEAVE TO AMEND COMPLAINT
TO INCLUDE PRAYER FOR RELIEF SEEKING PUNITIVE DAMAGES

PLAINTIFFS' MOTION FOR LEAVE TO AMEND COMPLAINT
TO INCLUDE PRAYER FOR RELIEF SEEKING PUNITIVE DAMAGES

that, years later, seriously injured the Plaintiffs in this case.[1] Boeing has known that toxic or contaminated air events happen on its airplanes since as early as the 1950s.[2] Toxic cabin air events occur on every type and model of Boeing airplanes that employ the "bleed air" system of cabin

[1] PX 0040, [redacted]

[2] PX 0334, 10/11/1955 at p. 2 (Presentation by Henry Redall at the 1955 the Society of Automotive Engineers Golden Anniversary Aeronautic Meeting on *Elimination of Engine Bleed Air Contamination:* On modern turbojet aircraft the compressor bleed air used for air conditioning is "increasingly subject to unacceptable contamination." Conclusion was that "every effort" should be made to minimize or eliminate leakage of engine oil into the air system); PX 1680A - Winder, *Hazardous chemicals on jet aircraft: case study - jet engine oils and aerotoxic syndrome, Current topics in toxicology,* Vol 3, p. 65-88 (2006) p. 2 ("In 1953, The US Aero-medical Association first expressed their concerns about the toxicity risks of cabin air contamination by hydraulics and lubricants")

IN THE CIRCUIT COURT OF COOK COUNTY, ILLINOIS
COUNTY DEPARTMENT, LAW DIVISION

Woods
Plaintiff(s),
v.
The Boeing Company,
Defendant(s).

No. 2015 L 6324
cons. with 2016 L 3846
Calendar R
Judge Christopher E. Lawler

ORDER

This Matter coming to be heard on Plaintiff's ① Motion to Compel Production of Documents and Further Testimony of Certain 215 Witness and ② Motion for Leave to Amend Complaint to Include Punitive Damages and Relief Seeking Punitive Damages and Counsel being present and the Court being fully advised in the premises:

① Plaintiff's Motion to Compel is granted;

② Plaintiff's Motion for Leave is granted, the Court grants leave for Plaintiffs to refile their Motion to Amend with Proposed Amended Complaint attached on or before 12/23/19.

③ CMC of 1/10/20 at 11 AM to stand.

Atty. No.: 31444
Atty. Name: Power Rogers + Smith
Atty. For: Pls
Address: 70 W. Madison
City/State: Chicago, IL
Telephone: 312-236-9381

ENTERED,
Judge Christopher Lawler
DEC 16 2019
Christopher E. Lawler, No. 2098
Circuit Court-2098

ORDER

Motion Granted

Cases

Captain Ron Weiland



August 17, 2016

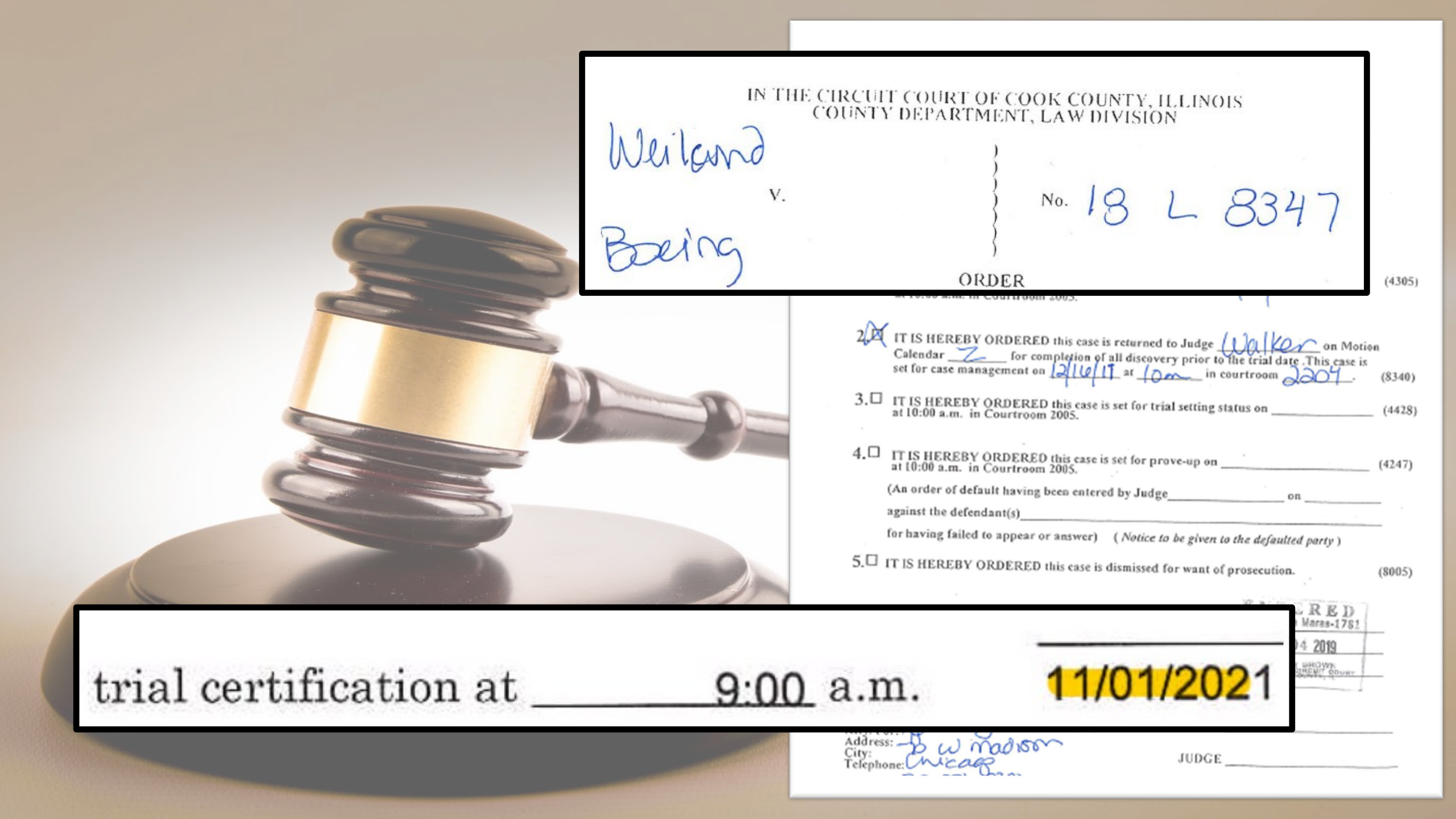


August 17, 2016: MIA to NY









IN THE CIRCUIT COURT OF COOK COUNTY, ILLINOIS
COUNTY DEPARTMENT, LAW DIVISION

Weiland

V.

Boeing

No. 18 L 8347

ORDER

(4305)

2. ☒ IT IS HEREBY ORDERED this case is returned to Judge Walker on Motion Calendar 7 for completion of all discovery prior to the trial date. This case is set for case management on 12/16/19 at 10am in courtroom 2204. (8340)

3. ☐ IT IS HEREBY ORDERED this case is set for trial setting status on _____ at 10:00 a.m. in Courtroom 2005. (4428)

4. ☐ IT IS HEREBY ORDERED this case is set for prove-up on _____ at 10:00 a.m. in Courtroom 2005. (4247)

(An order of default having been entered by Judge_____ on _____

against the defendant(s)_____

for having failed to appear or answer) (*Notice to be given to the defaulted party*)

5. ☐ IT IS HEREBY ORDERED this case is dismissed for want of prosecution. (8005)

ENTERED
Maras-1781
04 2019
CLERK'S OFFICE
CIRCUIT COURT

Address: 10 W Madison
City: Chicago
Telephone:

JUDGE _____

trial certification at 9:00 a.m. 11/01/2021

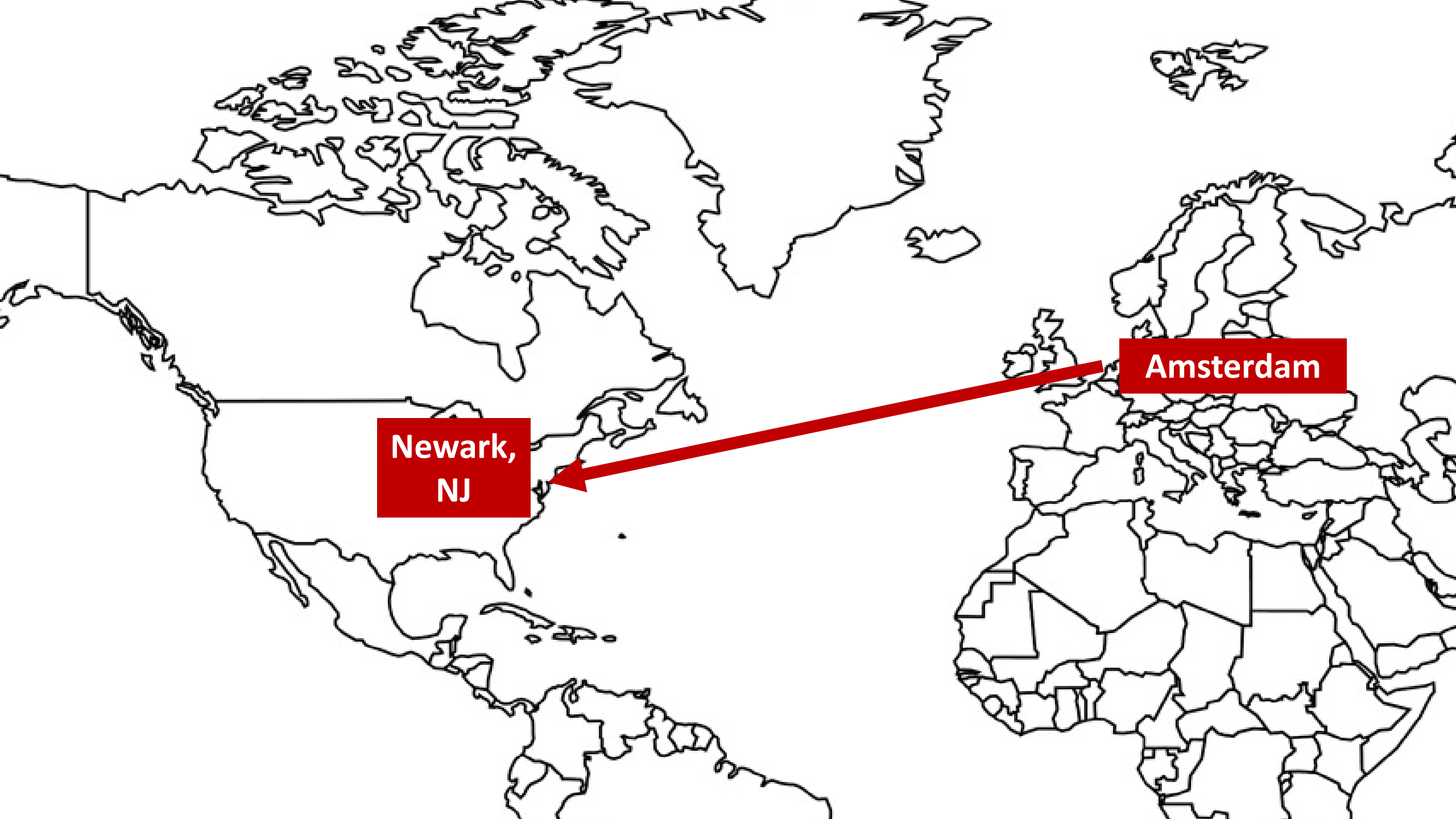
Curry & Cheung v. Boeing

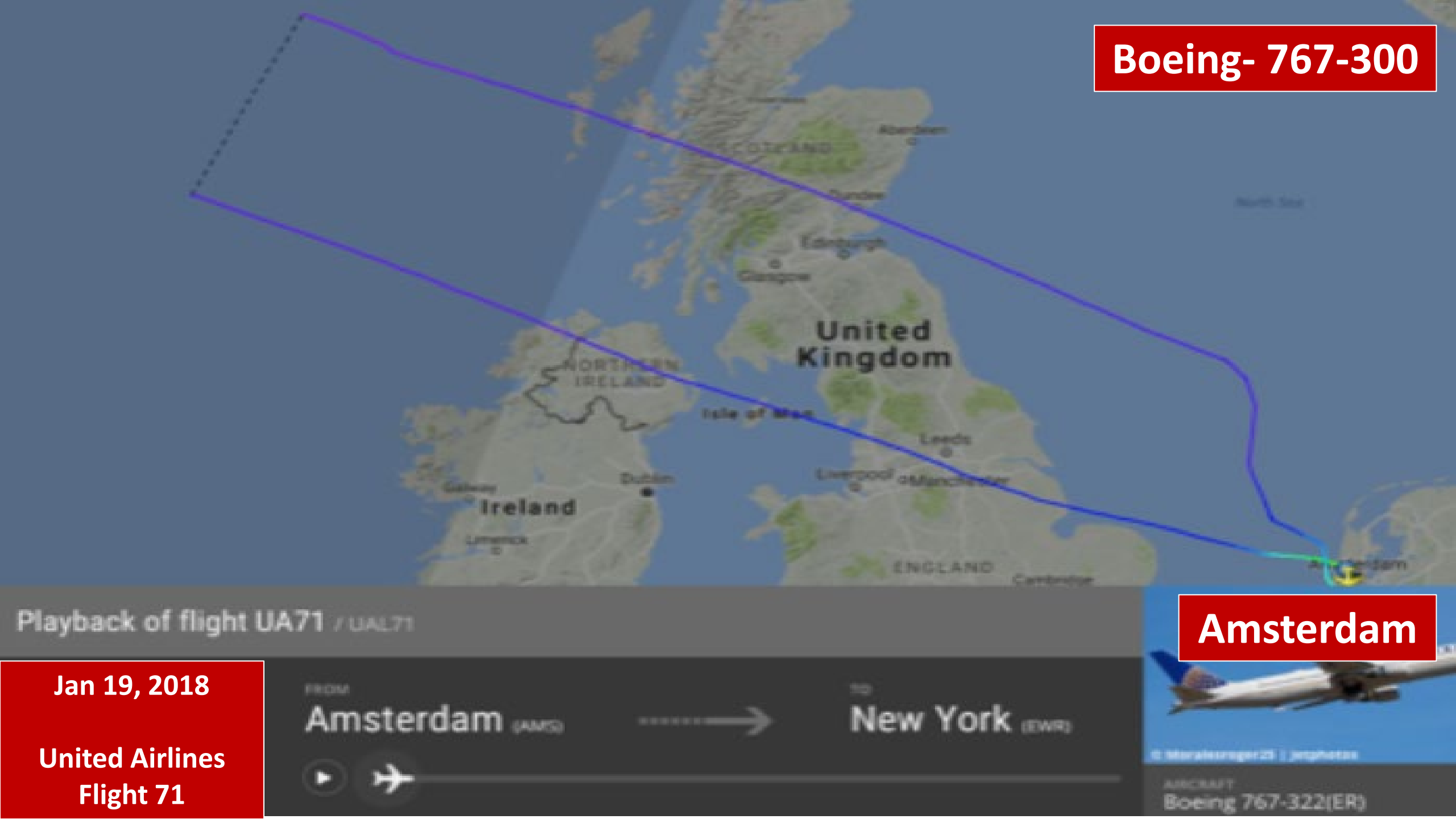


Linda Curry



Allen Cheung


Amsterdam
Newark, NJ


Boeing- 767-300
United Kingdom
Ireland
Playback of flight UA71 / UAL71
Amsterdam
Jan 19, 2018
United Airlines
Flight 71
FROM
Amsterdam (AMS)
TO
New York (EWR)
AIRCRAFT
Boeing 767-322(ER)

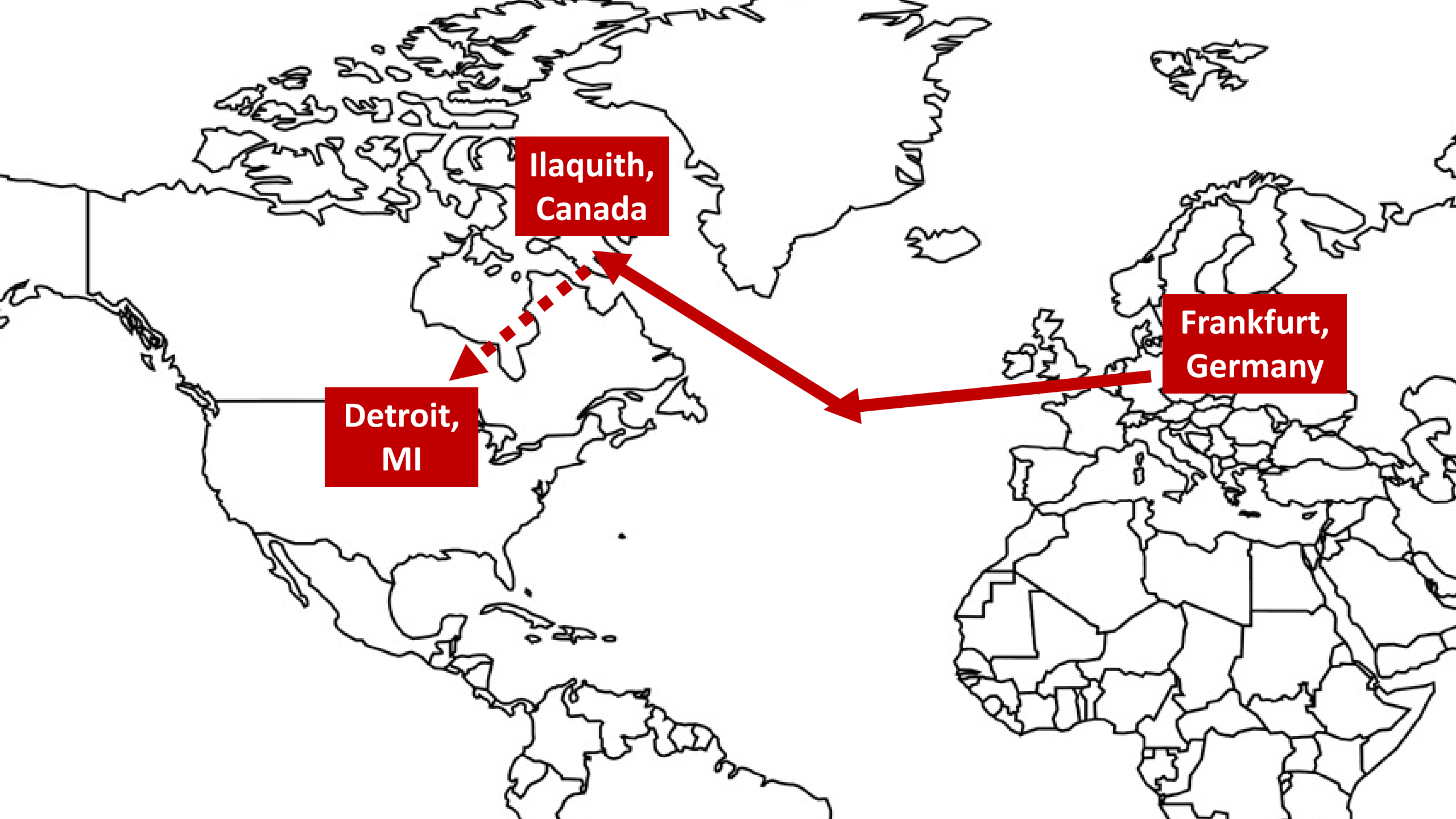
Milton, Spencer & Calvert v. Boeing








Frankfurt, Germany
Detroit, MI


Ilaquith, Canada
Frankfurt, Germany
Detroit, MI

Experts …



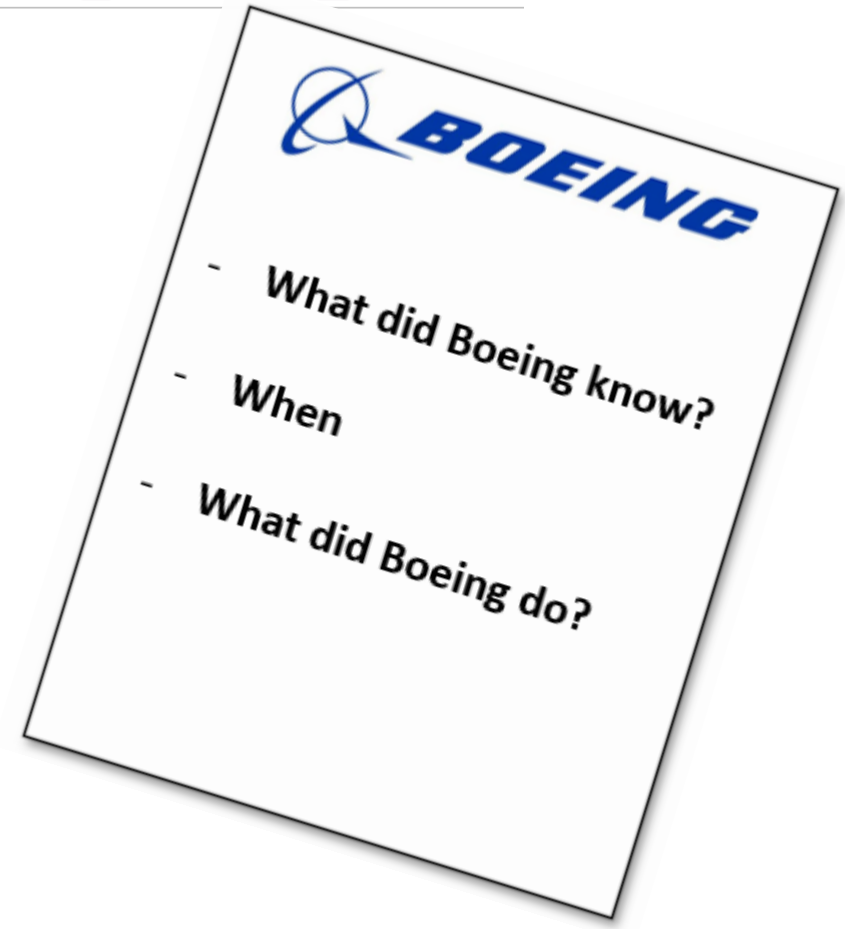
Air Quality Team





OUR Air Quality Team

Fresh eyes



Aeronautical Engineer

Airline Safety Manager

Pilot / Engineer

Aircraft Mechanic

OUR Air Quality Team

Medical Toxicologist

Analytical Chemist

Forensic Economist

Case Specific

Occupational Medicine

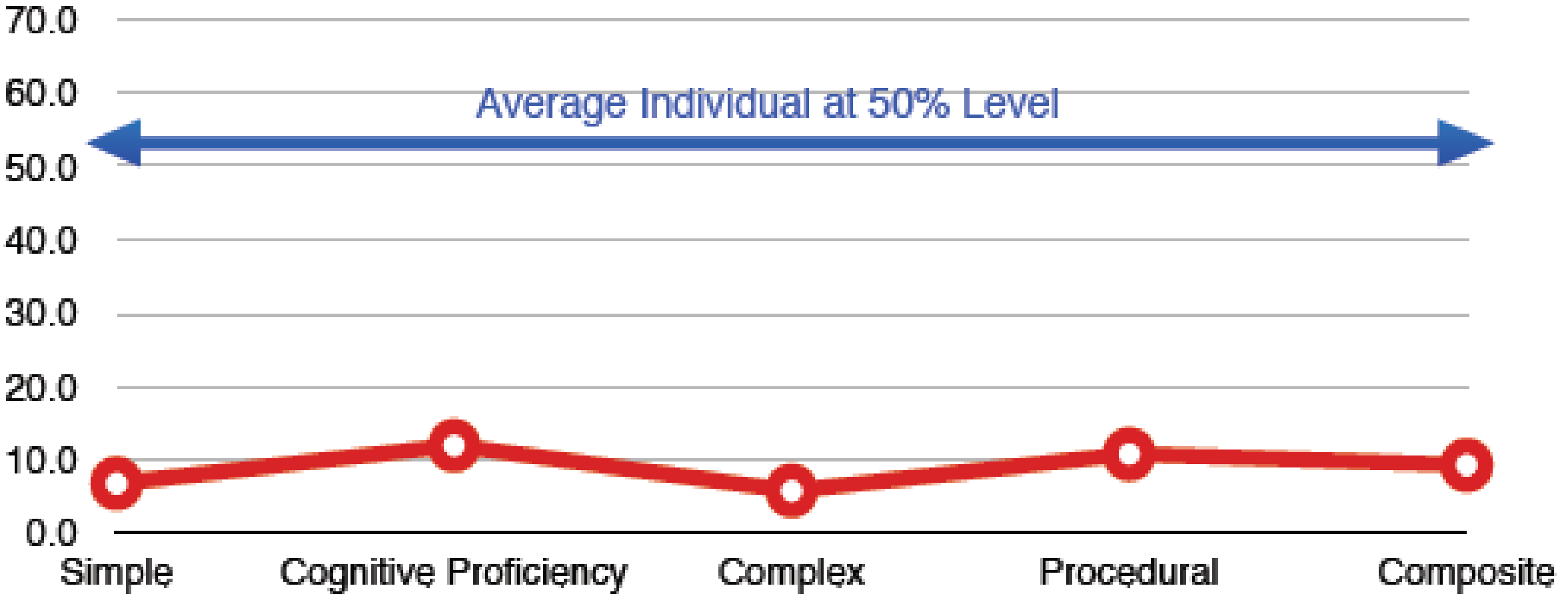
Neurologist

Neuro-Psychologist

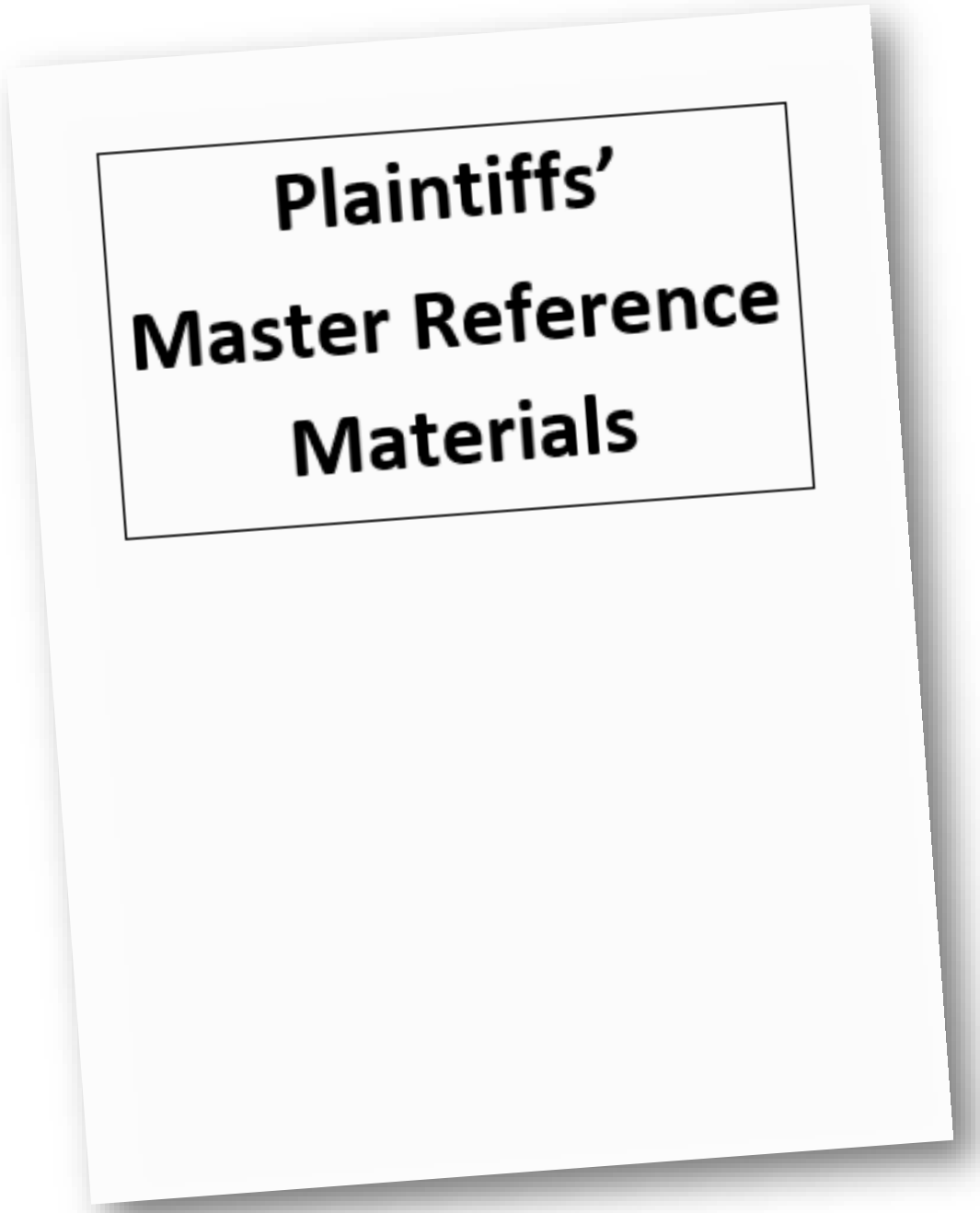
Vocational / Life Care

Neuro-Psychologist

The above data is listed as % rankings. For example on Simple Reaction Times the mean is 6.75% meaning that 93% of the general population is above these individuals. (The mean in the general population would be the 50% level.) Clearly these genetic strangers are affected with probable white matter changes consistent with toxic exposure. Obviously cognitive slowing and the inability to respond quickly to emergency situations would be contraindicated for any individuals involved in public safety including airline attendants. Note: Out of 25 data points, 23 were below a percentile ranking of 16% with 6 below the 5% level.



Air Quality Team created...



PLAINTIFF'S MASTER REFERENCE MATERIALS

INDEX

- **246 pages**
- **Single spaced**
- **Over 1,217 citations**

We will continue …

Injured Flight Crew



Injured Flight Crew Against Boeing



Injured Flight Crew Against Boeing Filed in Chicago



Aircraft Cabin Air International Conference 2021 (ACA 2021) – Proceedings

Conference: Online, 15-18 March 2021
Conference Director: Tristan Loraine
Publisher: London, UK: GCAQE (https://gcaqe.org)
Editors: Dieter Scholz, Susan Michaelis

AIRCRAFT CABIN AIR
International Conference 2021

History of Contaminated Air – From 1901 to 2021

LORAINE, Tristan
Spokesperson – Global Cabin Air Quality Executive (GCAQE)
E-Mail: tristan@tristanloraine.com

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Abstract

Purpose: This document identifies the historical aspects of aircraft contaminated air.
Findings: The problem was first known in early 1950s. There are over 150 pieces of research and other initiatives to date. It is an acknowledged flight safety issue. FAA and EASA are failing to mitigate to flight safety problem or protect crew and public health. We find increasing legal actions against airlines and aircraft manufacturers. Effective total cabin air filtration and onboard sensors are needed to enhance flight safety and protect public health.

Keywords

contaminated air, fume events, oil fumes, flight safety, bleed air, aerotoxic syndrome

1 Dawn of Aviation

The first flight took place in 1903, by 1909 the English Channel was flown and in 1919, Alcock and Brown crossed the Atlantic. In 1927, Charles Lindbergh flew solo non-stop from New York to Paris in 33.5 hours. Aviation progress was staggering. Aviation was here to stay.

To make air travel more comfortable and more economical, flight at higher altitudes was needed. To enable this, aircraft would need to be pressusrised. The first aircraft with a pressurised cockpit was the Engineering Division USD-9A (**Figure 1, Figure 2**), that flew in 1921 but the first pressurised commercial airliner was the Boeing Model 307 Stratoliner, which first flew in 1938.

How to cite this paper (ISO 690, Harvard): LORAINE, Tristan, 2021. History of Contaminated Air – From 1901 to 2021. *Aircraft Cabin Air International Conference 2021 (Online, 15-18 March 2021)*. London, UK: GCAQE. Available from: https://doi.org/10.5281/zenodo.5557722
Related presentation: https://doi.org/10.5281/zenodo.5514195
Review process: Editorial review.

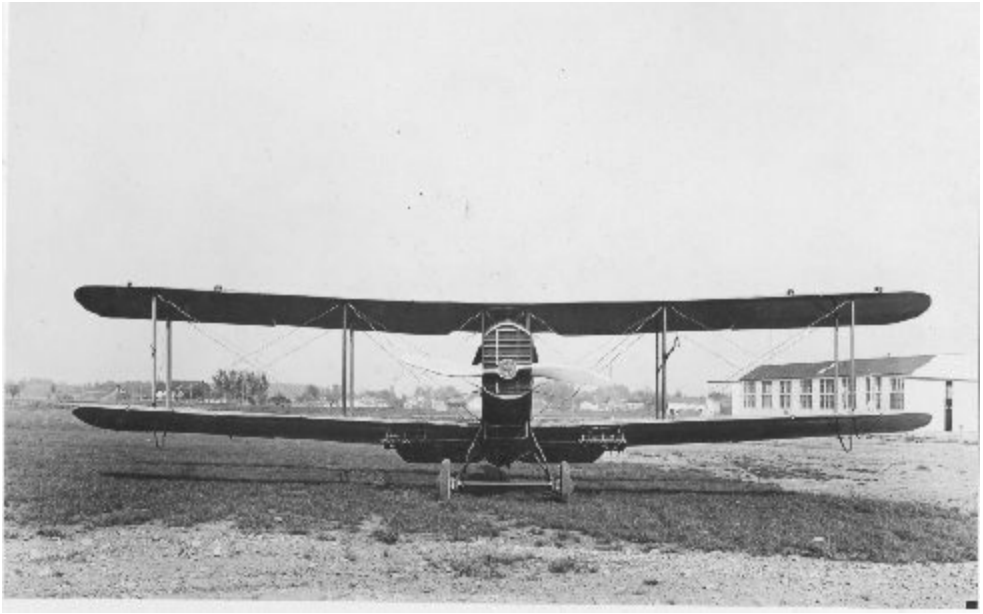


Figure 1 Engineering Division USD-9A.



Figure 2 USD-9A with pressurised cockpit (SDASM 2010).

2 Beginning of the Jet Age and Propeller Driven Commercial Aircraft

The following year, in 1939, aviation took another technological leap forward when the Heinkel He 178 (**Figure 3**) became the world's first aircraft to fly under turbojet power, and the first practical jet aircraft. Only 8 years later Chuck Yeager broke the sound barrier in October 1947.

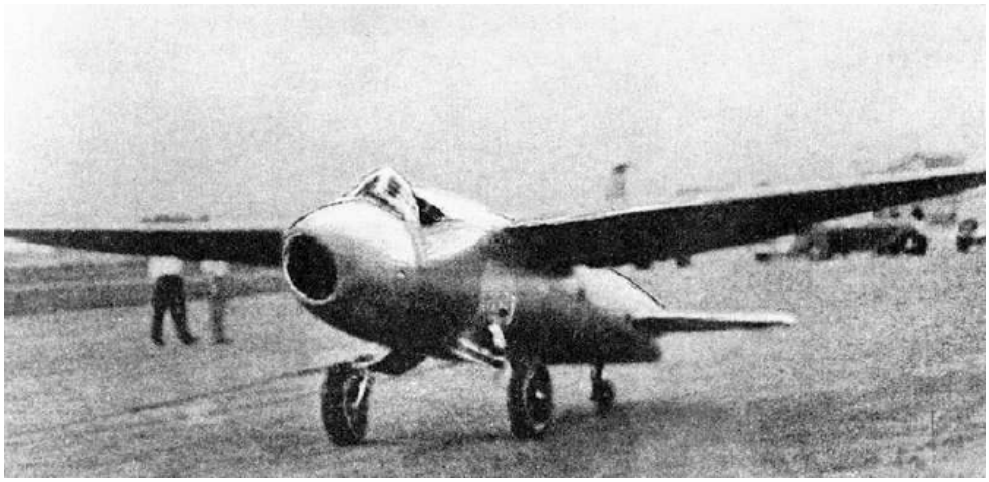


Figure 3 Heinkel He 178.

The Boeing Model 307 (**Figure 4**) used cabin superchargers to pump high volumes of air into the aircraft to provide an 8,000 foot cabin altitude whilst flying at 15,000 feet. The Cabin Blowers revolutionised aircraft and provided the air needed for pressurisation. Adverts from companies like AiResearch called them the 'New "Lungs" For The Luxury Airliners'. These very effective blowers flew on 1940s aircraft like the Lockheed L647/749 Constellation (**Figure 5**) and Boeing B-29 Superfortress.



Figure 4 Boeing Model 307 Stratoliner.



Figure 5 Lockheed L-647 Constellation.

However, the introduction of the jet engine offered a new way of pressurising the aircraft cabin - Air from the engine. When the Lockheed F-80 Shooting Star (**Figure 6**) flew in 1944, air was taken from the engine blower section and used to pressurise the cockpit. This provided an 18,000 foot cabin altitude whilst flying at 30,000 feet.



Figure 6 Lockheed F-80 Shooting Star (McLaren 2004).

"In the early 1950s, the J57 engine took jet engine design to new levels and air was bled off the compression section of the axial flow engine (**Figure 7**). These new engines operated at far higher internal temperatures and needed a new type of oil to replace the previously used mineral oil. These new oils developed under military specification MIL-L-7808 were man made synthetic oils known as Type One or Three centistoke oils." (Loraine 2019)

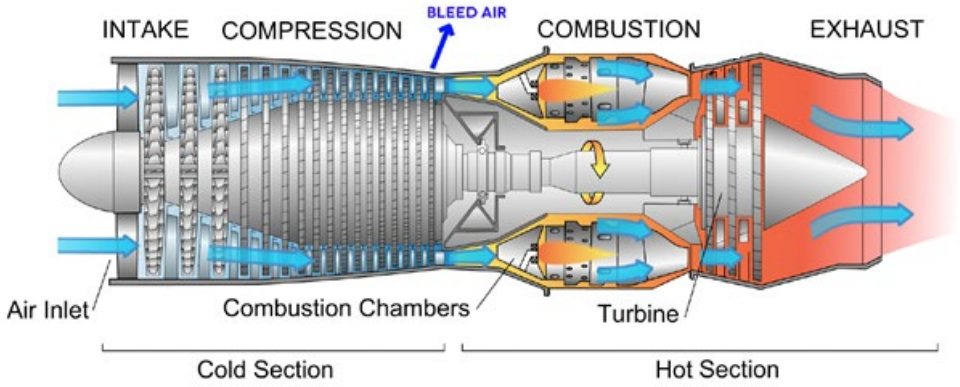


Figure 7 Extraction of bleed air from the compression section (GCAQE 2015).

As US military pilots started to fly these higher-powered aircraft with the new synthetic engine oils, the problem of contaminated air emerged. Reports of heated engine oil contaminating the unfiltered breathing air supply and impacting health and flight safety, soon started to emerge. The problem was linked to oil leaking past the engine bearing oil seals and contaminating the breathing air.

Numerous agencies and aircraft manufacturers investigated this emerging problem. The US Air Force concluded the toxicity was derived from the thermal decomposition of the oils base stock. They also predicted there would be increased toxicity as engine temperatures increased. (Treon 1955)

Single seat US military planes soon saw crews required to wear oxygen masks from take off to landing. This mitigated but did not resolve the problem.

3 Early Commercial Jet Aircraft

In the early commercial jet aircraft, to prevent oil contamination of the air supply (known as 'bleed air') turbo compressors were used on all the early US passenger jet aircraft such as the Boeing 707, Douglas DC-8, and Convair 880/990 (**Figure 8**). The corresponding switches and gauges could be found on the flight engineer's panel (**Figure 9**).



Figure 8 Convair 880.

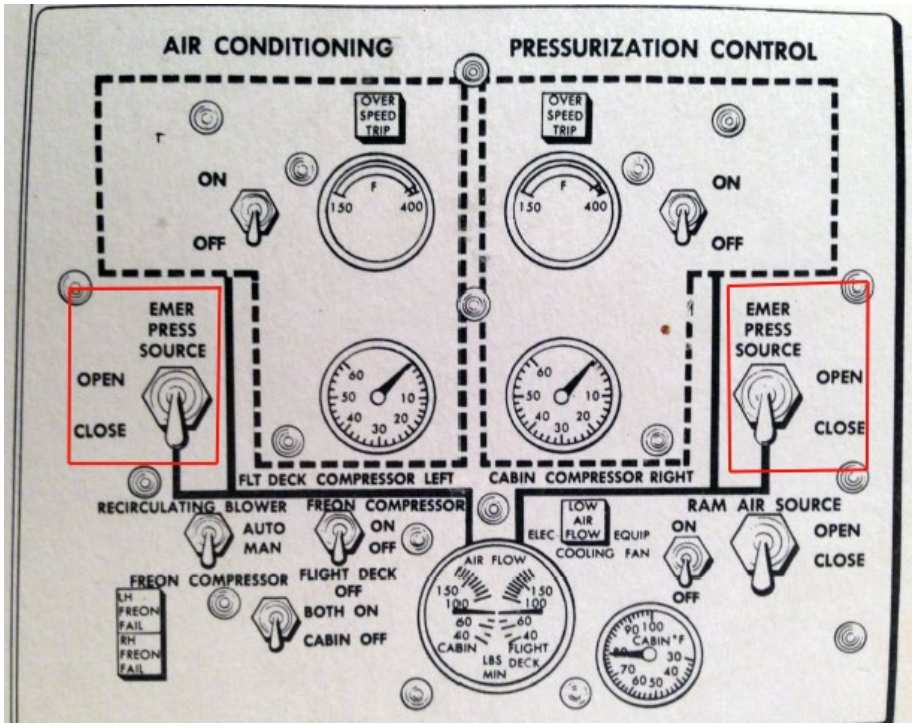


Figure 9 Cabin compressor switches on the flight engineer's panel (Convair 880).

However, turbo compressors were the effective solution but also the heaviest, most complicated and least economical option. Despite the known concerns in the US, two European aircraft manufacturers elected to use direct bleed air on the French Caravelle (**Figure 10**) and later versions of the British Comet aircraft.



Figure 10 Sud Aviation Caravelle (Garrard 1967).

Soon US aircraft manufacturers followed suit and in 1962 the British Vickers VC-10 aircraft became the last commercial airline to not use bleed air.

The industry had convinced itself that the air within the engine used to supply the bleed air, was of the same quality as the outside air. If there were to be occasional fume events, the air supplied by the bleed air system was deemed to be acceptable. (NRC 2002)

4 Contemporary Commercial Jet Aircraft

Reports of contaminated air continued over the next decades. It was only when the smoking ban on passenger jet aircraft arrived in the late 1980s, early 1990s that the number of fume events escalated.

By the end of 2000, the US Senate had been informed and an Australian Senate Inquiry had concluded that contaminated air was a health and flight safety issue. By 2007 air accident investigation departments had twice recommended all aircraft have contaminated air warning systems following a number of crew and pilot impairments and incapacitations in flight due to exposures.

In 2009, the Boeing 787 became the only aircraft to fly without using bleed air for pressurisation, it has a bleed free architecture utilising electrical compressors.

As of September 2021, no commercial jet airliner flies with any effective bleed air filtration or warning systems fitted.

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History of Contaminated Air From 1903 to 2021

2021 Aircraft Cabin Air Conference

Captain Tristan Loraine

GCAQE Spokesperson

1903 - 1st Flight



GCAQE
Global Cabin Air Quality Executive

1909 - 1st Channel Crossing



GCAQE
Global Cabin Air Quality Executive

1919 - 1st crossing of the Atlantic



1927 - 1st solo crossing of the Atlantic



1938 - 1st Pressurised Airliner



Boeing Model 307 Stratoliner

GCAQE
Global Cabin Air Quality Executive

1939 – 1st Jet Aircraft – He 178



1947 - 1st Supersonic Flight – X1



GCAQE
Global Cabin Air Quality Executive

1964 - Mach 3+ - XB-70



GCAQE
Global Cabin Air Quality Executive

1921 – 1st Pressurised Aircraft Engineering Division USD-9A





1938 - 1st Pressurised Airliner



Boeing Model 307 Stratoliner

Cabin Superchargers – 8,000ft cabin at 15,000ft.

GCAQE
Global Cabin Air Quality Executive

Cabin Blower - AiResearch - Garrett





Lockheed L-647/749 Constellation

First Flew: 1943

Cabin Blower - AiResearch - Garrett





Boeing B-29 Superfortress

First Flew: 1942

1944 – Lockheed F-80 Shooting Star



Air taken from the engine blower section is used to pressurise the cockpit.

GE J33-A-23 - Single-stage centrifugal flow - At 30,000ft cabin altitude was 18,000ft.

GCAQE
Global Cabin Air Quality Executive

1947 - Boeing 377 Stratocruiser



Carbon Monoxide Detectors and Filters
Sea level cabin at 15,000ft - Max 6.55 PSI

GCAQE
Global Cabin Air Quality Executive

1948 - Patent

PATENT SPECIFICATION 651,576

Date of Application and filing Complete Specification: July 10, 1948.

No. 18618/48.

Application made in France on July 11, 1947.

Complete Specification Published: April 4, 1951.

Index at acceptance:—Class 4, E, R.

COMPLETE SPECIFICATION

Improvements in and relating to Aircraft with Pressurized Cabins

We, Societe Nationale D'Etude et de Construction de Moteurs D'Aviation, a French Body Corporate, of 150, Boulevard Haussmann, Paris, (Seine), France, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

In aircraft, rotary centrifugal compressors have already been proposed for feeding a hermetically sealed cabin; such compressors being driven from an auxiliary engine, of the power plant of the aircraft. In such a construction two engines are thus necessary; the main propelling engine and the said auxiliary engine.

It has also been proposed to arrange on an aircraft an engine operated by a medium including air, a sealable compartment, and a supercharging device arranged to conduct air from the atmosphere to the engine by way of the said compartment. Such a construction presents the disadvantage that the air is conducted along a path of considerable length prior to its inlet opening in the engine, resulting in losses of energy.

Also, in aircraft provided with an internal combustion gas turbine power plant comprising combustion chambers with a gas turbine driving a multi-stage air compressor, it has been proposed to arrange means for supercharging a sealed compressor and at least one pipe connecting the said compressor to the said pressurized cabin.

The said aircraft is characterized by a peripheral compressed air collector disposed on the casing of the said compressor and peripherally connected to the said casing.

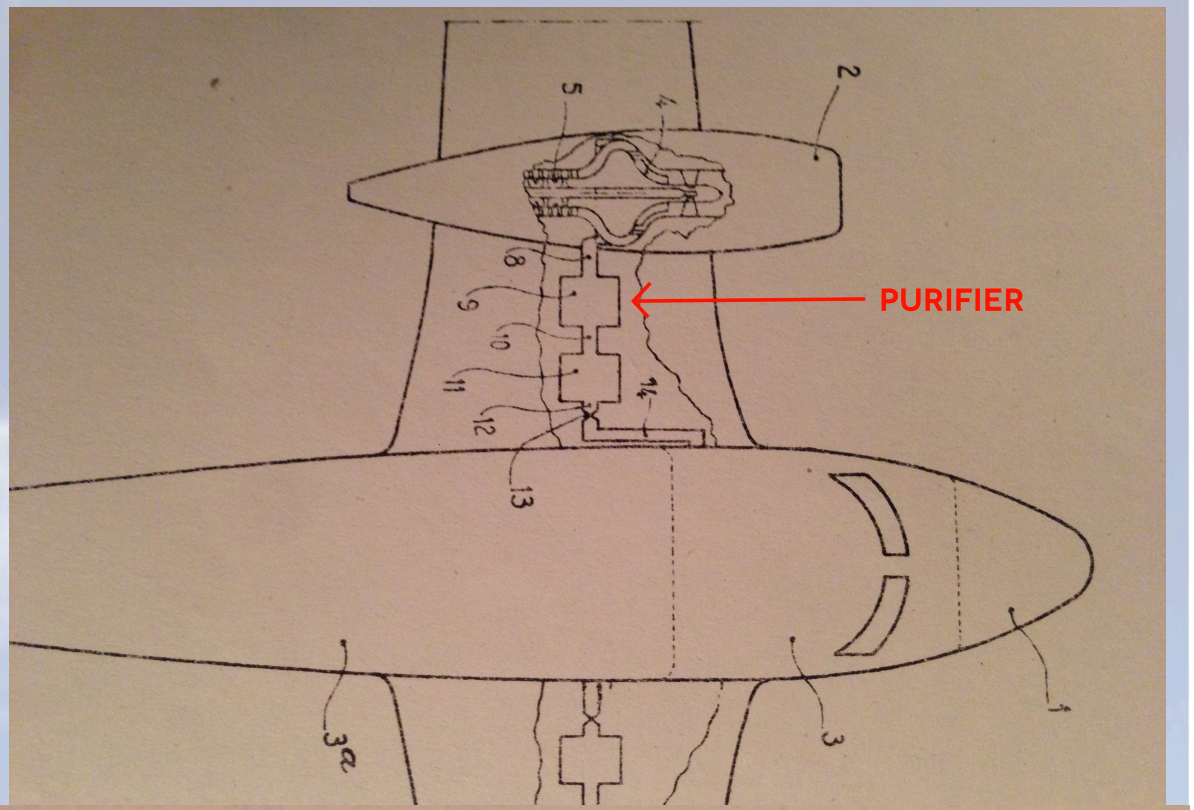
The present invention contemplates, *inter alia*, the following aircraft:

1. Those in which the peripheral compressed air collector is disposed after the diffusor of the compressor.

2. Those in which the peripheral compressed air collector disposed after the diffuser is connected to the casing of the rotor of the compressor at a place where the flow is stabilized and where the speed of flow is least.

3. Those in which the peripheral compressed air collector is connected to the casing of the rotor of the compressor opposite to the latter so as to create a regeneration of the boundary layer of air flow in the rotor compressor.

By the adoption of this last arrangement, whenever an increase in the speed of the air in the rotor of the compressor tends to remove the air from the wall of the casing and to transform the streamline flow of the air into a turbulent movement which brings about a loss of output from the compressor, the feeding of the air collector by the casing of the rotor of



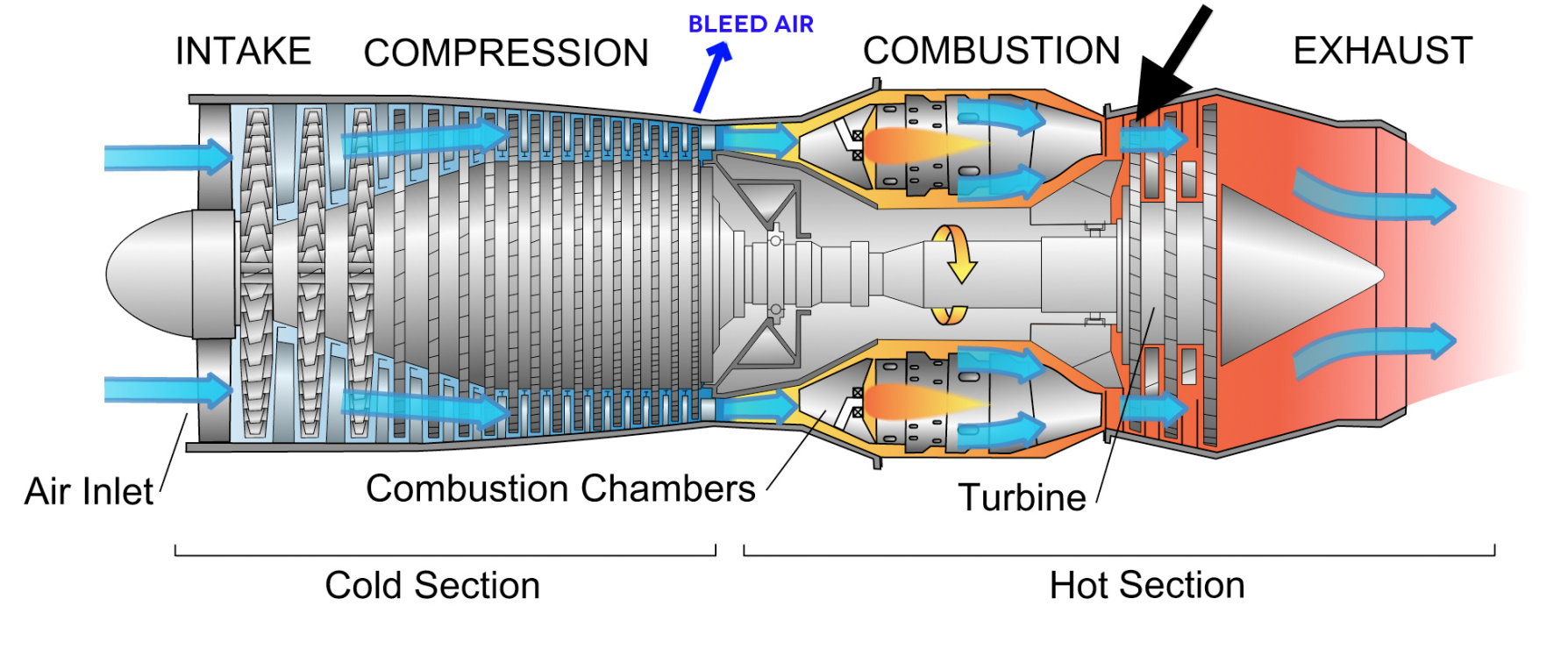
Improvements in and relating to Aircraft with Pressurized Cabins

We, Societe Nationale D'Etude et de Construction de Moteurs D'Aviation, a French Body Corporate, of 150, Boulevard Haussmann, Paris, (Seine), France, do hereby declare the nature of this invention

compressor and at least one pipe connecting the said compressor to the said pressurized cabin.

The said aircraft is characterized by a peripheral compressed air collector dis-

Jet engine and ‘Bleed Air’



1952/53 – J57 Engine

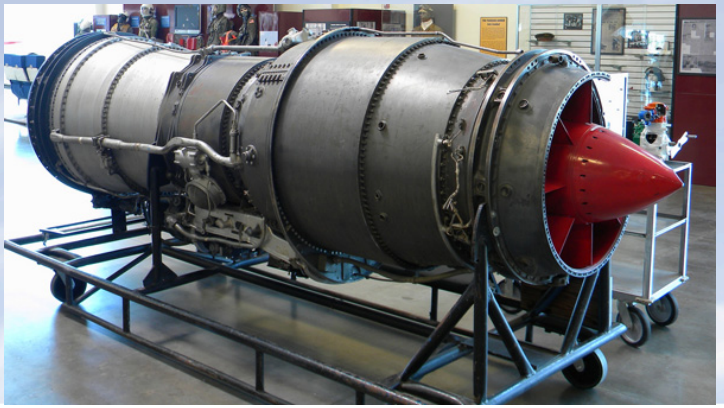


B-52 and the F-100 – Bleed Air



The J57 (JT3) Engine was the first Pratt & Whitney-designed turbojet.

Early use of MIL-L-7808 Synthetic oil Type I or 3 centistoke jet oils





18 December 1953

Boeing Document D-14766-2

B-52 Decontamination Program

- Testing of a filter system
- The possible toxic effect of the contamination is still unknown.
- Smoke or haze is reported in only a few flights.
- Obvious increases in the contamination level were noted during changes in engine power conditions.

Oils – Mineral v Synthetic

- Early gas turbine engines in the 1940's used mineral oils.
- **Type I Oils** (or 3 centistoke - viscosity at 99C)
  Mil-L-7808 specification introduced.

  Fully synthetic (ester)-based oils - worked well at first but were soon stressed beyond their limits.
- **Type II Oils** (5 centistoke viscosity at 99C)

  Mil-L-23699 specification - early '60s

  Also called "2nd generation" jet oils e.g. Mobil Jet Oil II
- **Type III Oils – 3rd Generation**

  Developed late '70s and early '80s - enhanced oxidative and thermal stability characteristics e.g. Mobil Jet Oil 254
- **Type IV Oils – 4th Generation**

  e.g. Mobil Jet Oil 291

An often asked question..

How do synthetic jet oils differ from synthetic automotive oils?

Synthetic jet oils differ significantly from synthetic automotive oils in base stock.

Automotive oils use synthetic hydrocarbon base oils with less high temperature capability which are more suited to the automotive engine operating environment.

Synthetic jet oils also contain organophosphates like TCP as an anti wear additive or PAN as an anti oxidant.

15 January 1954

Engine Compressor Bleed Air Contamination Study
XC-132 Project - R.W. Maddock – Douglas

- J-57 & T-57 engine contamination problems.
- The paper states the problem was first reported in the flight-testing of the B-52 in 1952.
- "Apparently the occurrence is completely erratic, with no predictable pattern since contamination has occurred at all modes of airplane operation, such as take-off, high altitude cruise, descent and taxi. So far there is no known condition or sequence of conditions, which will reliably reproduce the trouble."

Oil Bearing chamber

CRANFIELD UNIVERSITY

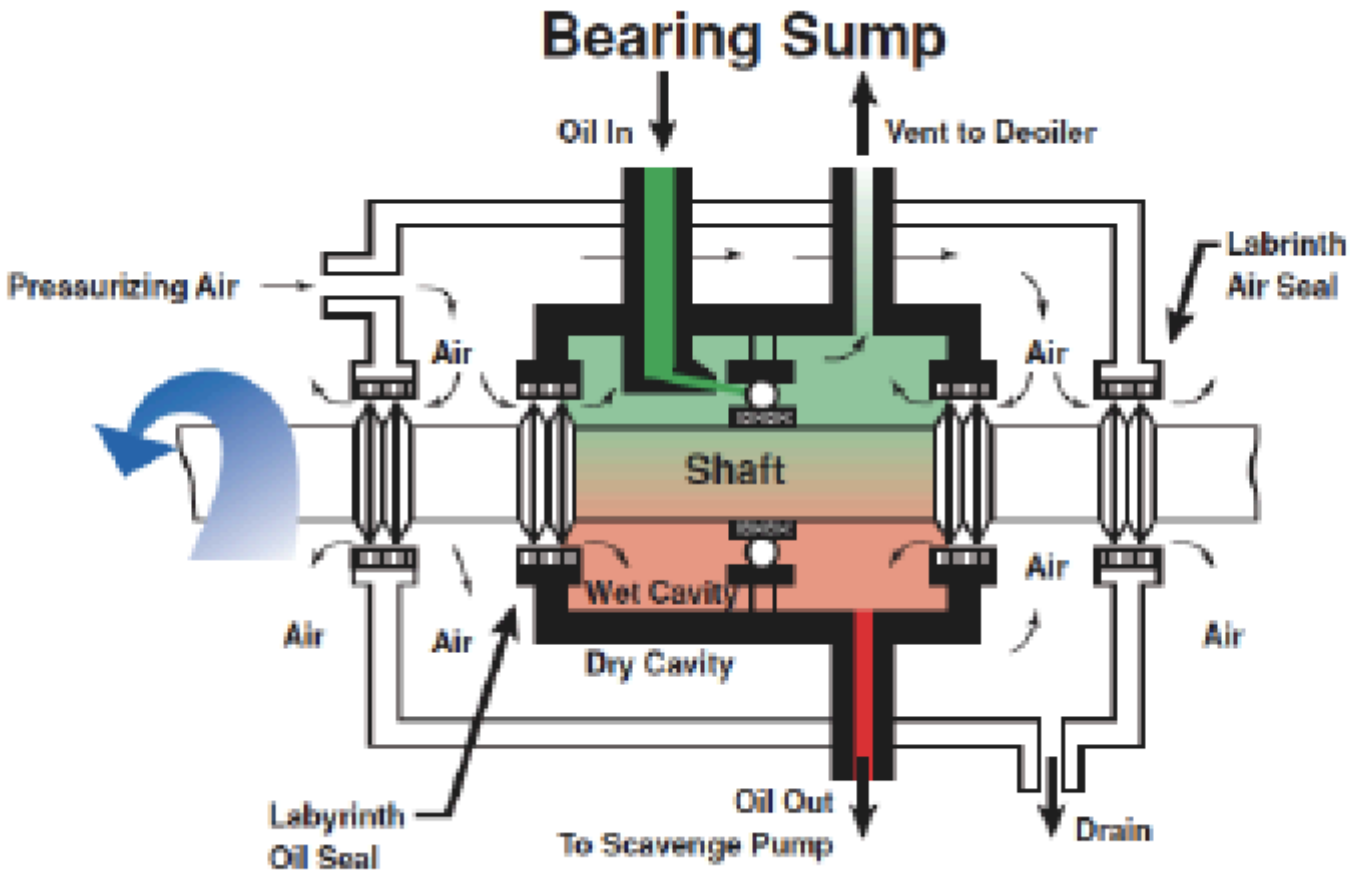
Susan Michaelis

IMPLEMENTATION OF THE REQUIREMENTS FOR THE PROVISION OF CLEAN AIR IN CREW AND PASSENGER COMPARTMENTS USING THE AIRCRAFT BLEED AIR SYSTEM

Transport Systems
Safety and Accident Investigation Centre

MSc
Academic Year: 2011 - 2016

Supervisors: Graham Braithwaite, Tony Jackson
June 2016





15 May 1954



"At approximately 1530 hours on 15 May 1954, I was flying aircraft number 52-1436, an RB-57A, in a three (3) plane formation from Shaw Air Force Base, South Carolina. Approximately 40 minutes after take-off while flying over an overcast at 7000 feet, I experienced blurred vision, became nauseated and experienced considerable dizziness. I recall no strange or unpleasant odors, nor did I taste anything out of the ordinary. I did feel a definite dryness of mouth and throat. This condition lasted possibly a minute or two. As I became more aware of the situation or nearly to the passing out point I recall dropping back from the formation and opening the clear vision window and unhooking the oxygen mask. Fresh air from this open window seemed to relieve the unpleasant conditions I felt."

WILLIAM J. VAN EVERY
1st Lt, USAF

GCAQE
Global Cabin Air Quality Executive

1954 – Dash 80 (Boeing 707)

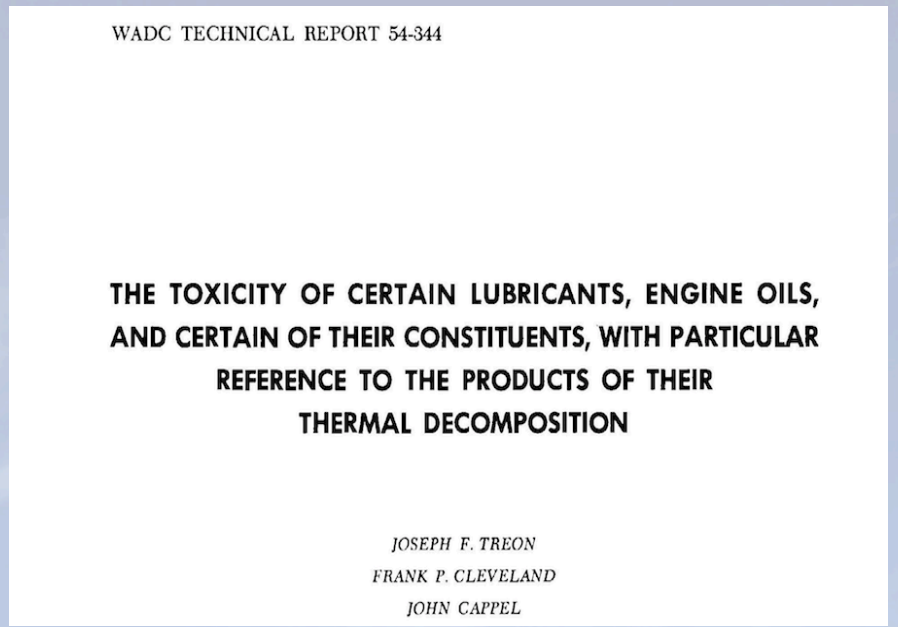




Turbo compressors

1954 - Treon et al. USAF

- Toxicity derived from thermal decomposition of oils base stock
- Increased toxicity with higher temperatures



WADC TECHNICAL REPORT 54-344

THE TOXICITY OF CERTAIN LUBRICANTS, ENGINE OILS, AND CERTAIN OF THEIR CONSTITUENTS, WITH PARTICULAR REFERENCE TO THE PRODUCTS OF THEIR THERMAL DECOMPOSITION

JOSEPH F. TREON
FRANK P. CLEVELAND
JOHN CAPPEL

Feb 1955 - CABIN AIR CONTAMINATION

Cabin Air Contamination in RB-57A Aircraft - Ted A. Loomis, Captain, MC and Stephen Krop, Ph. D.

AD 56539 – Armed Services Technical Information Agency – Army Chemical Center – Maryland.

- The present studies involving exposure of humans to the cabin air at the engine test facility while the lubricant was sprayed into the intake of the engine demonstrated that illness can occur as a result of such exposure. The nature of the illness is predominantly the result of irritant agents in the air, and results chiefly in eye, nasal, and pharyngeal irritation. If exposure is continued pulmonary and gastric symptoms develop.
- Smoke or fog is not an adequate indication that excessive lubricant is being used by the engine as symptoms appeared before amounts of the lubricant great enough to produce smoke were present.
- It would be reasonable to expect similar illness following prolonged exposure to even lower concentrations of the lubricant (and/or its breakdown products) than were used in this study.

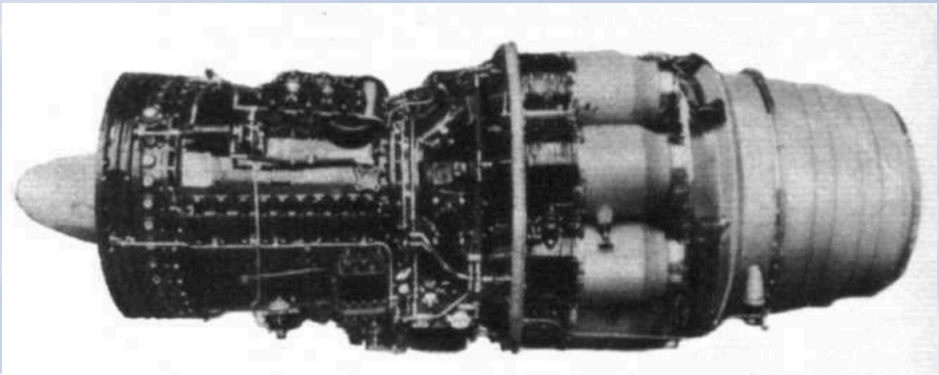
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Meanwhile in Europe…
1953 / ???? – de Havilland Comet
1955 – Caravelle





1st airliners to use bleed air for pressurisation



Common link…

Both used
Rolls-Royce Avon engines

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Global Cabin Air Quality Executive

October 1955

Elimination of Engine Bleed Air Contamination

Henry A. Redall – North American Aviation

Aware of oil contamination issue for last two years – suspect compressor bearing seals main source – different aircraft with basically the same engine have contradicting reports – in-depth look at filter options.

Solutions: “The Separate Compressor As A Solution – This method of eliminating contamination is considered to be the most positive… also the heaviest, most complicated and most expensive.”

The contamination in our present airplanes is not toxic.

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1958 – Douglas DC-8



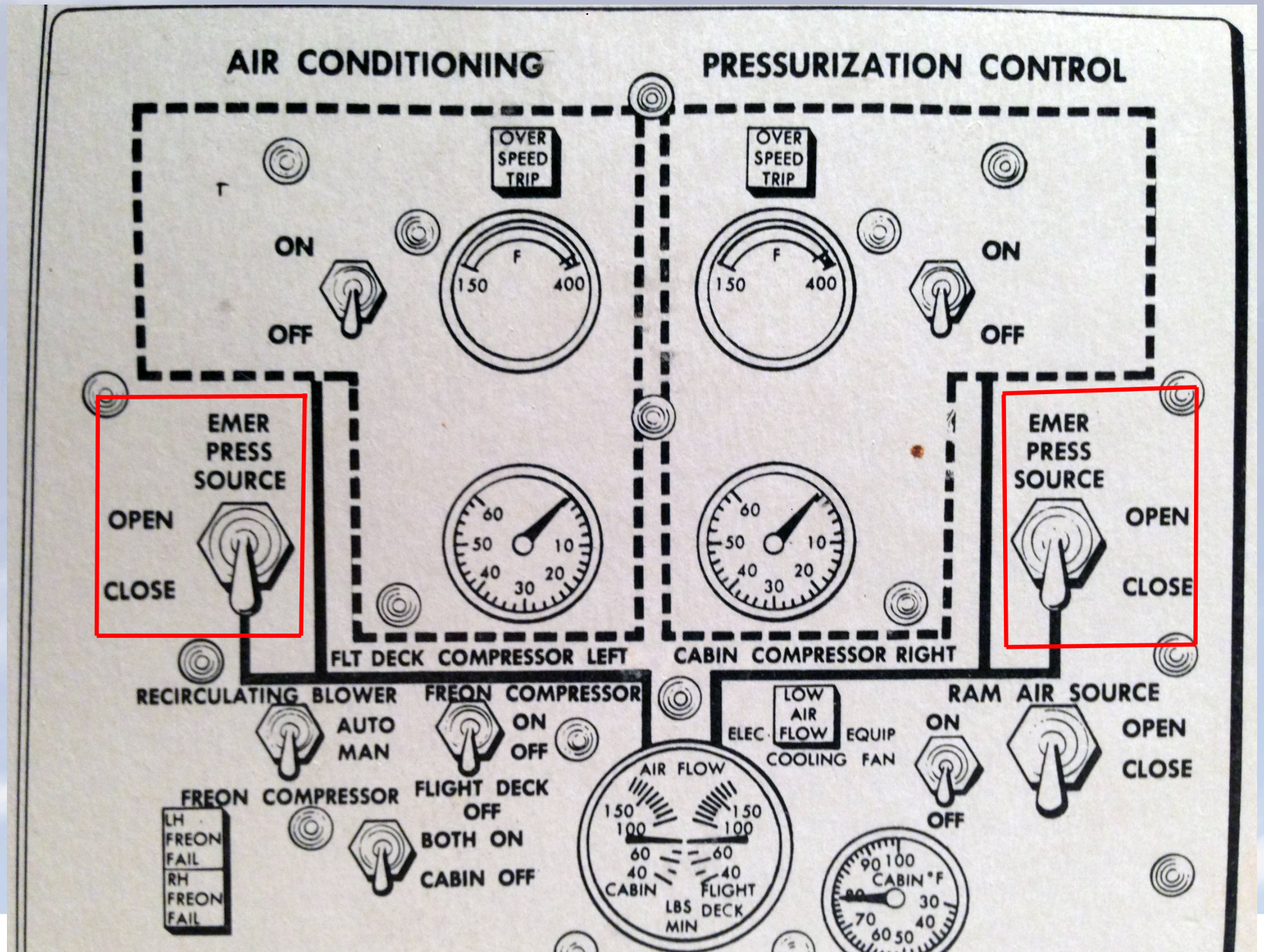
Turbo compressors

1959 – Convair 880/990



Turbo compressors

1959 - CV 880 – Cabin Compressors



1962 - VC-10



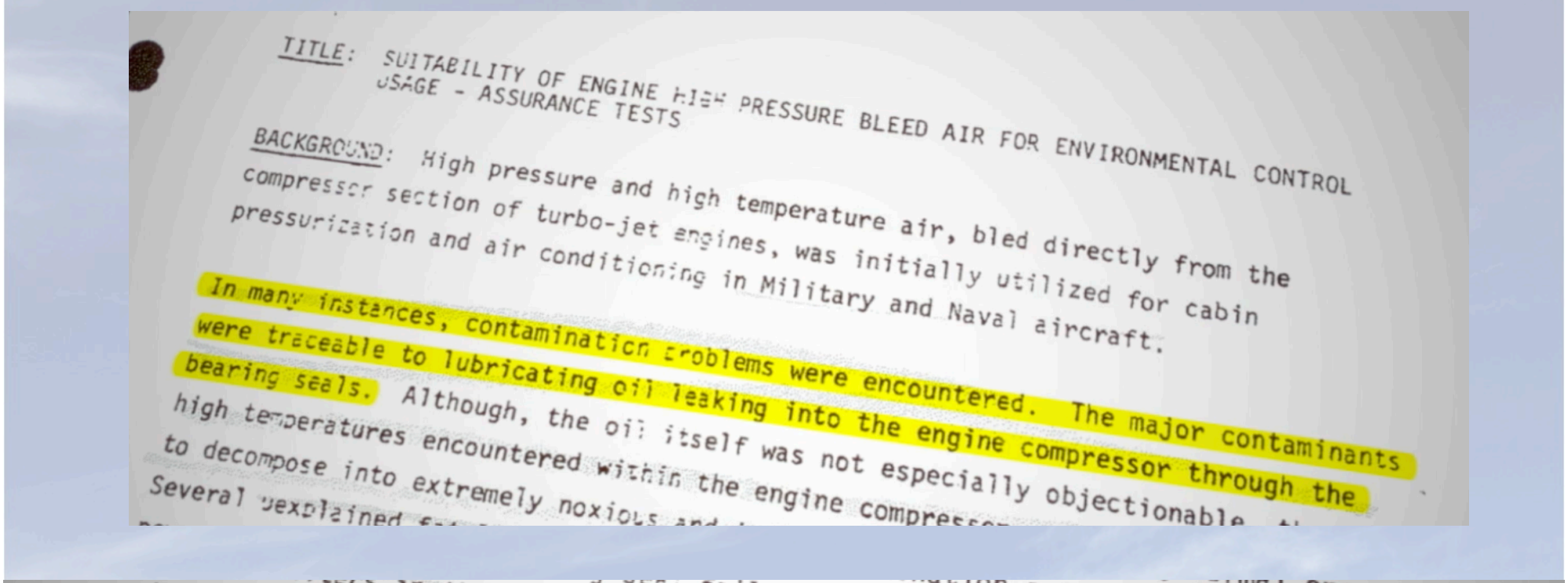
Turbo compressors

1963 - Boeing 727



Bleed Air

1966 - DOUGLAS



TITLE: SUITABILITY OF ENGINE HIGH PRESSURE BLEED AIR FOR ENVIRONMENTAL CONTROL USAGE - ASSURANCE TESTS

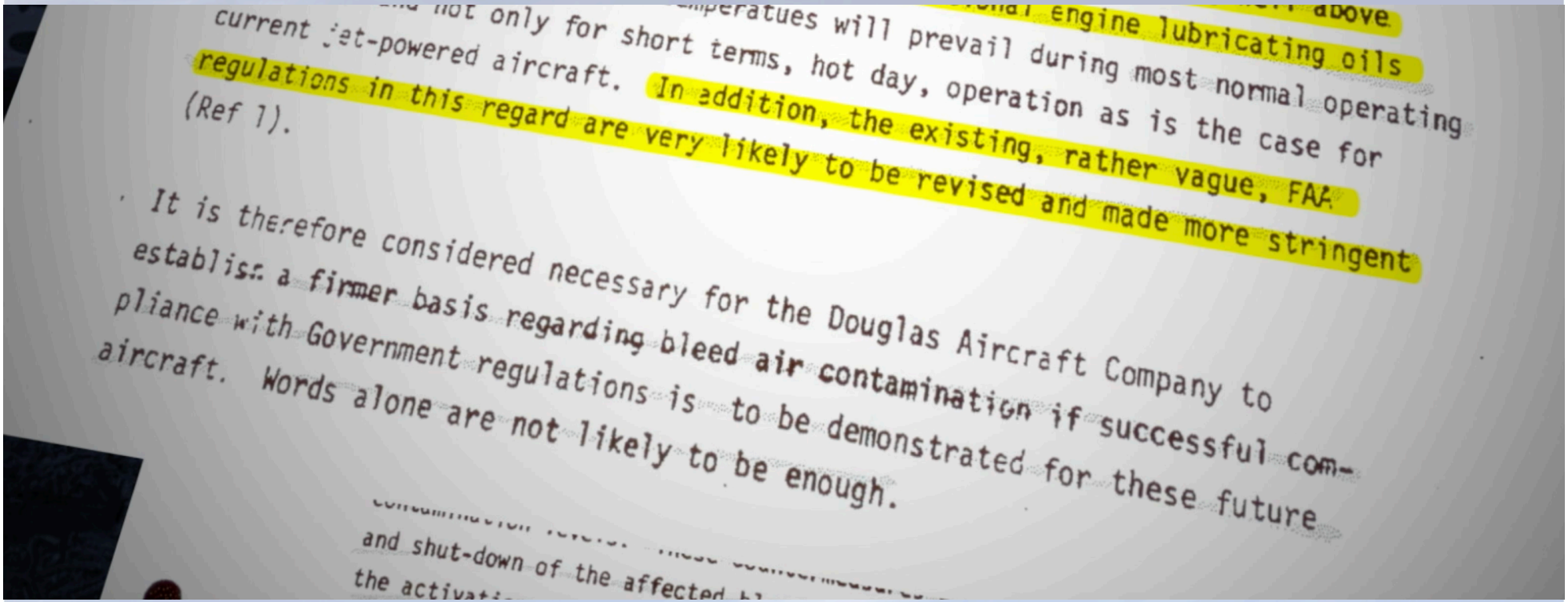
BACKGROUND: High pressure and high temperature air, bled directly from the compressor section of turbo-jet engines, was initially utilized for cabin pressurization and air conditioning in Military and Naval aircraft.

In many instances, contamination problems were encountered. The major contaminants were traceable to lubricating oil leaking into the engine compressor through the bearing seals. Although, the oil itself was not especially objectionable, the high temperatures encountered within the engine compressor to decompose into extremely noxious and Several unexplained

failure. The airframe manufacturers installed isolating any engine suspected of supplying contaminated air in multi-engine aircraft. The Navy issued an operational order (still in effect) requiring that all crew members of turbine powered aircraft with direct bleed air systems installed use 100% oxygen from takeoff to landing.

The lessons gleaned from this early Military in designing the current DC-9

1966 - DOUGLAS



engine lubricating oils above

peratues will prevail during most normal operating

not only for short terms, hot day, operation as is the case for current jet-powered aircraft. In addition, the existing, rather vague, FAR regulations in this regard are very likely to be revised and made more stringent (Ref 1).

It is therefore considered necessary for the Douglas Aircraft Company to establish a firmer basis regarding bleed air contamination if successful compliance with Government regulations is to be demonstrated for these future aircraft. Words alone are not likely to be enough.

and shut-down of the affected

1973



ANALYTICAL CONSIDERATIONS CONCERNED

WITH CEPHALAGIA ON THE DC-10

Prepared by:

J. G. Gaume, M.D., Manager

Aviation Medicine and Safety Research

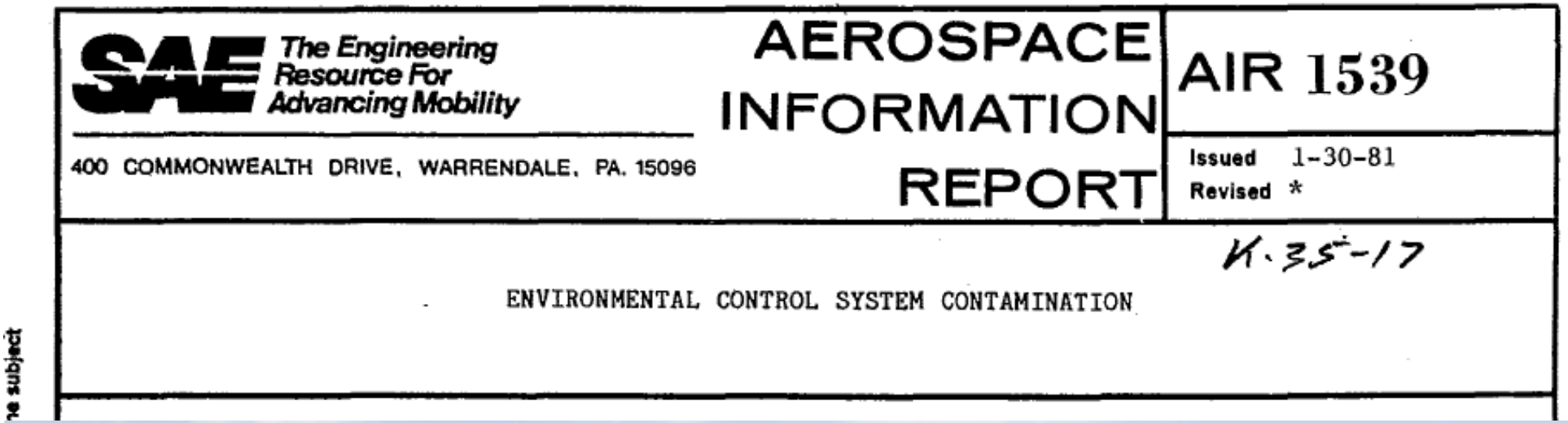
Science Research

20 February 1973

After preliminary examination of these possible sources, it appeared to be quite probable that the source of the headaches could be contaminants derived from the engine bleed air source for cabin pressurization. This report is limited to consideration of this aspect, and the analysis of the report quoted in the introduction of this report. The contaminant, from its odor and description by personnel affected, would appear to be an irritant gas, although it may well be accompanied by asphyxiants such as CO or CO_2. This report elaborates on this premise.

1981 – SAE AIR 1539

At temperatures above 320^{0}C this oil breaks down into irritating and toxic compounds.



SAE The Engineering Resource For Advancing Mobility

400 COMMONWEALTH DRIVE, WARRENDALE, PA. 15096

AEROSPACE INFORMATION REPORT

AIR 1539

Issued 1-30-81
Revised *

K-35-17

ENVIRONMENTAL CONTROL SYSTEM CONTAMINATION

e subject

September 1983

Dr. James Cone M.D.



- Dr Cone, a US occupational doctor links contaminated air exposures on aircraft with health effects in those exposed.
- Dr Cone writes a paper for the US union APFA in 1984 recommending crews have some form of portable breathing protection.

San Francisco General Hospi
Medical Cen
OCCUPATIONAL HEALTH CLINI
Building 9, Room 109
(415) 821-5391

September 6, 1983

INTERIM REPORT #1
Association of Professional Flight Attendants

I. Introduction/Background

On June 28, 1983 the Occupational Health Clinic was contacted by Connie Stevens, Safety and Health Regional Chairperson, Association of Professional Flight Attendants representing flight attendants at American Airlines. She requested technical assistance with evaluating a problem experienced by flight attendants working the American Airlines flights between San Francisco and Honolulu, over the past year, who reported symptoms including decreased appetite, respiratory distress, nosebleeds, sinus congestion, pain in nostrils, and blockage of eustacian tubes to ears, beginning during these flights and lasting up to three weeks.

Flight attendants reportedly smelled fumes with a foul smell at various times during the flights, described at "musty" or "like dirty socks." Initial reports were limited to DC10-10's with occasional reports from flight attendants flying on DC10-30's and 747 aircraft. These reports had been made to the company through the flight log, and the initial hypothesis of the possible cause of this problem was an engine oil, Mobil Jet II. The company subsequently indicated that they would replace the engine oil with a new oil (RM 254, from Mobil). However, reports of continued odors and persistent and recurrent symptoms have come to the attention of the APFA, and flight attendants have expressed concern over continued possible exposures and long-term health effects.

II. Actions Taken To Date

On June 26, 1983, Buck Cameron, Industrial Hygienist for the Occupational Health Clinic, met with Connie Stevens, APFA, to discuss the problem. Buck Cameron agreed to obtain further information regarding the exact nature of the oils and other possible exposures by obtaining Material Safety Data Sheets from the manufacturer.

On August 9, Buck Cameron, Industrial Hygienist and James E. Cone, Chief, Occupational Health Clinic, met with Connie Stevens, APFS, to further discuss the problem. Further details on process description were obtained from Connie Stevens, and a preliminary draft of a questionnaire which the APFA planned to send to a group of its members was reviewed. A revised questionnaire was drafted, and planned to be distributed to all flight attendants on the SFO-HNL flights, to cover a total of 5 flights each. An additional group of Flight Attendants flying a similar route from Los Angeles was selected to be surveyed to determine if they were experiencing similar problems with unusual odors or symptoms. The identical questionnaire was to be distributed to the LA flight attendants.

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Global Cabin Air Quality Executive

1985
Mobil Oil



Mobil Oil Corporation

3225 GALLOWS ROAD
FAIRFAX, VIRGINIA 22037-0001

April 22, 1985

Mr. J. M. Smith
Avco Lycoming Division
550 So. Main Street
Stratford, CT 06497

Airline operators reporting odor problems

Odor more likely due thermal degradation of oil

- e.g. Oil leaking past seal into compressor

Changed base stock to reduce odour



1988 – 1990 – 2000 Smoking ban on aircraft

The U.S. ban on in-flight smoking began with domestic flights of two hours or less in April 1988, extended to domestic flights of six hours or less in February 1990, and to all domestic and international flights in 2000.

Significant increase in reporting of contaminated air events after the smoking ban.

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Global Cabin Air Quality Executive

1990s - Ansett

- "There used to be in existence a BAe146 Odour Inquiry Committee"
- Ansett/East West
- Established Early 1990s

- The source of the odours has been identified as predominantly Mobil jet oil 2 leaking past oil seals in the engines and/or auxiliary power unit into the air conditioning system.

Ansett & FAAA evidence to Australian senate Inquiry, 1999

GCAQE
Global Cabin Air Quality Executive

1991 – British Aerospace



Internal BAe ‘COMPLAINT OR DIFFICULTY REPORT’ dated the 10th March 1991 states:

“Can Hatfield provide a definitive statement on the medical implications of fumes/smells in the cabin… **Dan Air cabin crew have complained of headaches and nausea**…

and goes on to say:

“despite a 2 year wait we still have no statement on Health and Safety.

Can you please hasten an answer on this point.”

1991



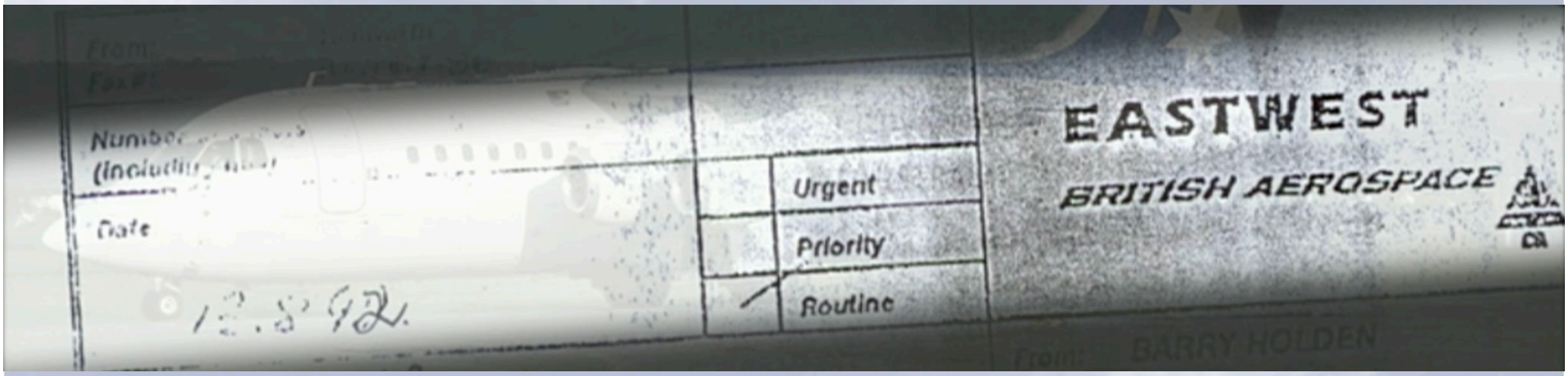
Dan Air memo dated 11 June 1991 raises the concern that:

> "**The possible medical implications associated with smells/ odours. Cabin staff had complained of headaches, nausea and sore throats.** The problem had been referred to the company doctor."

The memo also states that the East West representative had advised that:

> "**Captains were making a Public Announcement to passengers and apologising for the "sweaty socks" smell.**"

1992



In a fax dated 12th August 1992 from BAe to Ansett/East West, a BAe representative argues that the problem of contaminated air lies not with the engines but with the APU and states:

"BAe are introducing a costly filtering system to mask the rubbish coming from another vendors product."

5 August 1992

Australian Government
Australian Transport Safety Bureau

ATSB

ATSB report 199202471 VH-EWJ BAe 146-300

"After take-off, the engine bleed air was switched on and an unpleasant smell was evident in the cockpit, **one cabin attendant placed on oxygen**.

APU oil leaked into the air conditioning system."

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Global Cabin Air Quality Executive

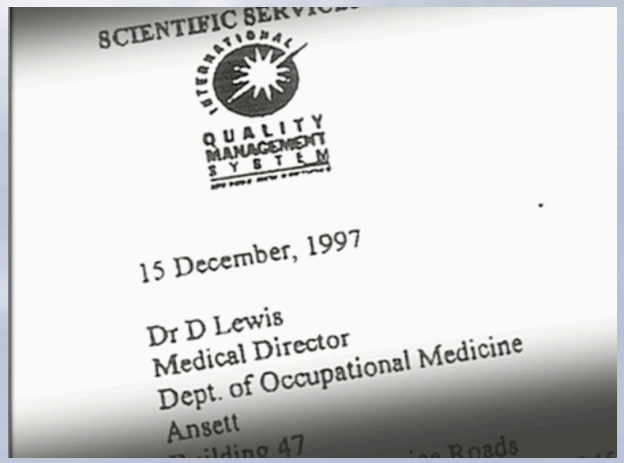
18 May 1994

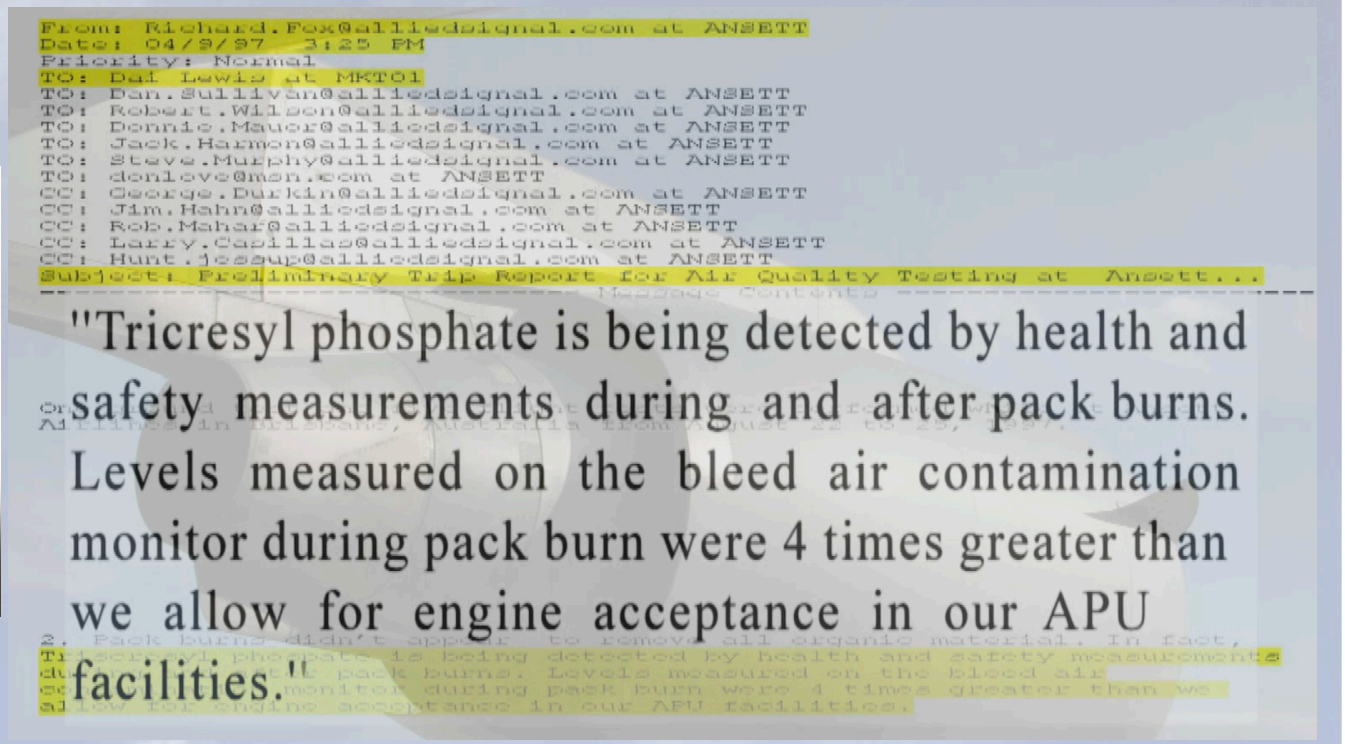
Airliner Cabin Air Quality: Hearing Before the Subcommittee on Aviation of the Committee on Public Works and Transportation, House of Representatives





1997





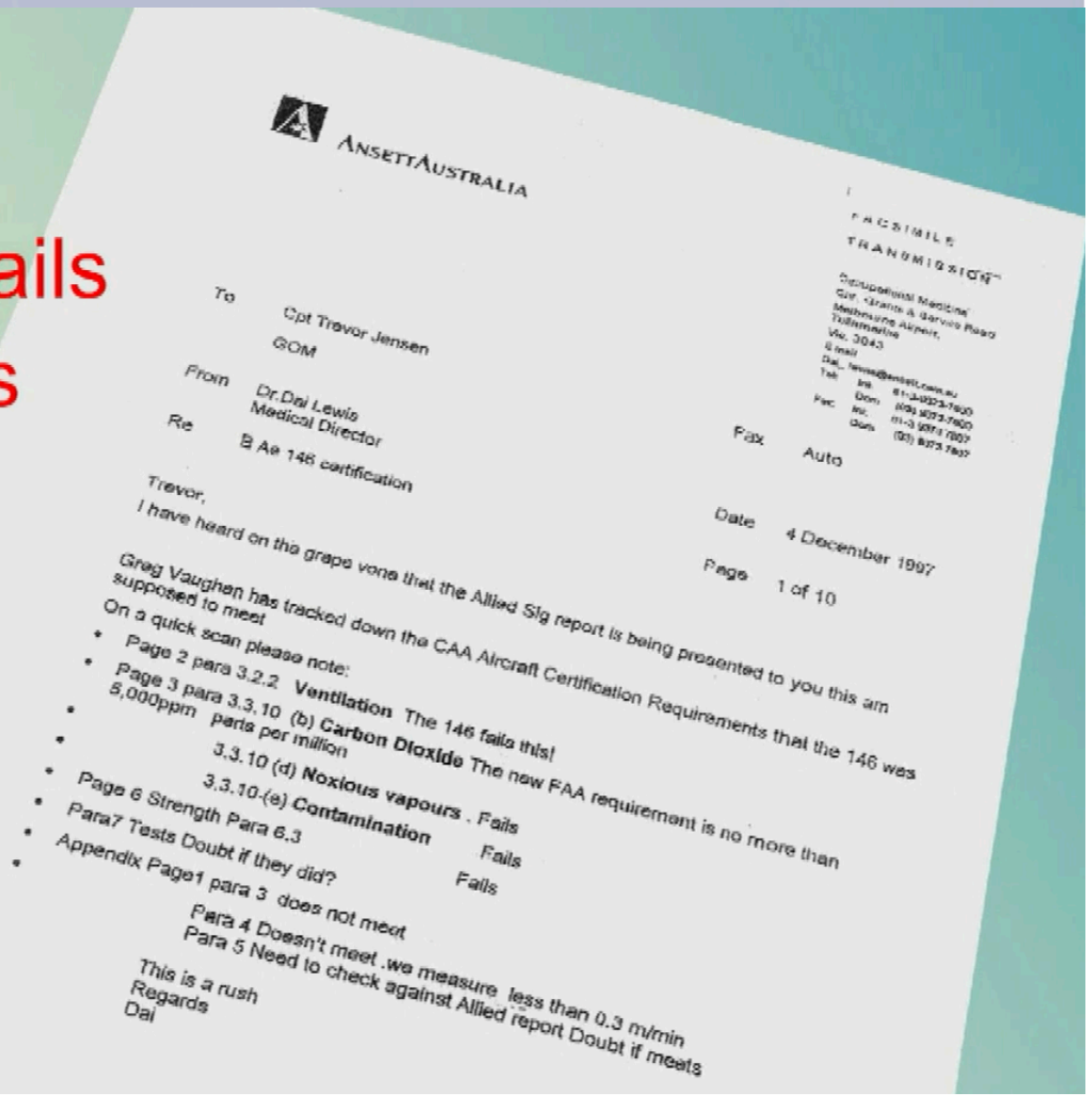
A December 1997 letter to the Medical Director of Ansett Airlines reveals that **tricresyl phosphate was detected** in an aircraft cabin.

A representative of the engine and APU manufacturer in an email to numerous Ansett Airlines employees states that they are finding contaminated air at 4 times the level they would expose their own workers to as well as **tricresyl phosphate**.

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Global Cabin Air Quality Executive

4 December 1997

Ventilation Fails
Noxious vapours Fails
Contamination Fails



ANSETT AUSTRALIA

FACSIMILE TRANSMISSION

To Cpt Trevor Jensen
GOM

From Dr.Dai Lewis
Medical Director

Re B Ae 146 certification

Fax Auto

Date 4 December 1997

Page 1 of 10

Trevor,
I have heard on the grape vone that the Allied Sig report is being presented to you this am

Greg Vaughan has tracked down the CAA Aircraft Certification Requirements that the 146 was supposed to meet

On a quick scan please note:

- Page 2 para 3.2.2 **Ventilation** The 146 fails this!
- Page 3 para 3.3.10 (b) **Carbon Dioxide** The new FAA requirement is no more than 5,000ppm parts per million
- 3.3.10 (d) **Noxious vapours** . Fails
- 3.3.10-(e) **Contamination** Fails
- Page 6 Strength Para 6.3 Fails
- Para7 Tests Doubt if they did?
- Appendix Page1 para 3 does not meet
- Para 4 Doesn't meet ,we measure less than 0.3 m/min
- Para 5 Need to check against Allied report Doubt if meets

This is a rush
Regards
Dai

1998



Ansett Airlines consensus statement

“short term symptoms associated with odours reported on the BAe 146 and other types are substantiated.”

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Global Cabin Air Quality Executive

4 February 1999

UK Government states:

“The inhalation of mist (containing tricresyl phosphate), which can be produced by high pressure systems, or direct contact with the skin, would be hazardous.”

“TCP is toxic.”



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1999



The Compensation Court of New South Wales reviewing the claim of Alysia Chew against her former employers, that she was:

"Exposed to fumes, toxic substances and other irritants whilst carrying out her duties as a flight attendant"

And finds in favour of Alysia Chew, stating that she had:

"Suffered injury arising out of and in the course of her employment."

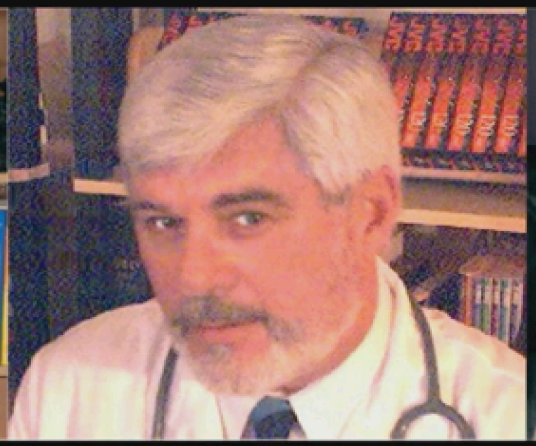
GCAQE
Global Cabin Air Quality Executive

20 October 1999

aerotox-pub . AEROTOXIC Syndrome (Public)

Founded: October 20, 1999

A public eGroup for discussions regarding disease in the Aerospace Environment relating to toxic exposures of Passengers, Aircrew, and Ground Workers, who present with symptoms consistent with what is presently known as "AEROTOXIC Syndrome".


12 November 1999



Malmo event

Both pilots incapacitated from exposure to oil fumes in the descent





GCAQE
Global Cabin Air Quality Executive



2000

UK House of Lords – BALPA Submission

The memorandum concludes by stating:

- “**we are at a stage where progress appears to be slow or non-existent**. We are aware of the fact that change can take time, however, **in cases where the health and safety of passengers and crew are concerned, we feel that matters should be treated with the appropriate urgency**.”

7 November 2000 - Boeing 757

A/C Type :	B757	**Occurrence Number :**	**200008363**
Flight Phase :	Cruise	**Occurrence Date :**	07 Nov 2000
Classification :	Serious Incidents	**Location :**	
Events :	Smoke / Fumes (not engine) Crew Illness / Incapacitation Engine Malfunction	**Location Info :**	

Pretitle :
Serious Incident : Oily metallic smell evident on flight deck. Flight crew partially incapacitated, numerous ATC calls missed. AAIB Field investigation.

Precis :
Oily metallic smell had also been evident during previous sector. On this occasion, numerous ATC calls were missed, prompting ATC to ask a/c if everything was all right. P1 then forget to slow a/c during approach until reminded to do so at 3.7d. Crew unaware that they were becoming partially incapacitated. Recurred 11.11.2000, strong smell on flight deck after engine start and throughout the flight. As P1 developed significant headache in and after the flight and an inability to concentrate, he withdrew from the remaining duty. Following this and other reported events, the engine overhauler has worked with the engine manufacturer to develop

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Global Cabin Air Quality Executive



1999 - 2000
Australian Senate Enquiry









"The report of course told us exactly what we had suspected and from the evidence we had received we discovered in fact that all jet aircraft from time to time have fumes that infect the air-conditioning and the BAe 146 aircraft was one of the worst."

GCAQE
Global Cabin Air Quality Executive

SAFETY REGULATION GROUP

FLIGHT OPERATIONS DEPARTMENT COMMUNICATION

CIVIL AVIATION AUTHORITY

2000

Flight Operations Department, Aviation House, Gatwick Airport South, Gatwick West Sussex, RH6 0YR

17/2000

3 INCAPACITATION PROCEDURES

3.1 There have been a number of recent incidents where, due to smoke or fumes entering the aircraft, both pilots of a Multi-Pilot aircraft have been affected to the extent that their ability to operate the aircraft may have been impaired. This highlighted two important training points; incapacitation drills and the use of oxygen masks.

3.2 Incapacitation Drills

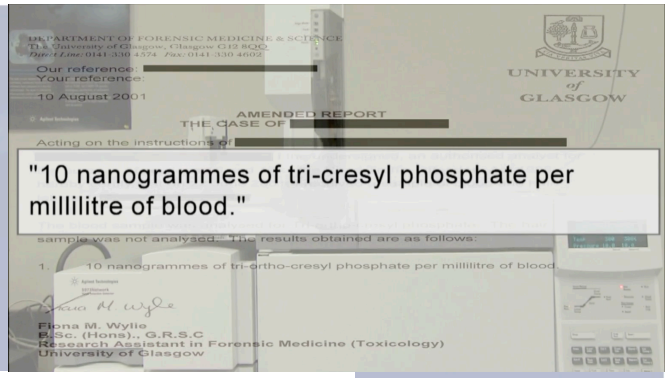
Incapacitation drills have been designed to ensure the continued safe flight of a Multi-Pilot aircraft in the event that one of the pilots becomes incapacitated. The situation where both pilots become incapacitated at the same time has been considered so remote that no procedures have been evolved to cope with the occurrence. However, it may be possible in the event of a malfunction in the engine or air conditioning systems which causes toxic fumes to enter the flight deck as has happened in a recent incident. Operators should, therefore, consider this possibility and provide some guidance to their crews, including cabin staff, to be aware of the chance of such an event.

3.2.1 The first action in the event of smoke or fumes in the flight deck should be for the flight crew to don oxygen masks and establish communications.

GCAQE Global Cabin Air Quality Executive

2001

TOCP in a Captain's blood



DEPARTMENT OF FORENSIC MEDICINE & SCIENCE
The University of Glasgow, Glasgow G12 8QQ
Direct Line: 0141-330 4574 *Fax:* 0141-330 4602

Our reference:
Your reference:

10 August 2001

UNIVERSITY *of* GLASGOW

AMENDED REPORT
THE CASE OF [redacted]

Acting on the instructions of Dr Alan R. Downie, The Consulting Rooms, 21 Neilston Road, Paisley PA2 6LW, I the undersigned, an authorised analyst for the purpose of sections 15 and 16 of the Road Traffic Offenders Act 1988, hereby certify that on 22 June 2001, I received a sample of blood and hair labelled

The blood sample was analysed for Tri-ortho-cresyl phosphate. The hair sample was not analysed. The results obtained are as follows:

1. 10 nanogrammes of tri-ortho-cresyl phosphate per millilitre of blood.

2002

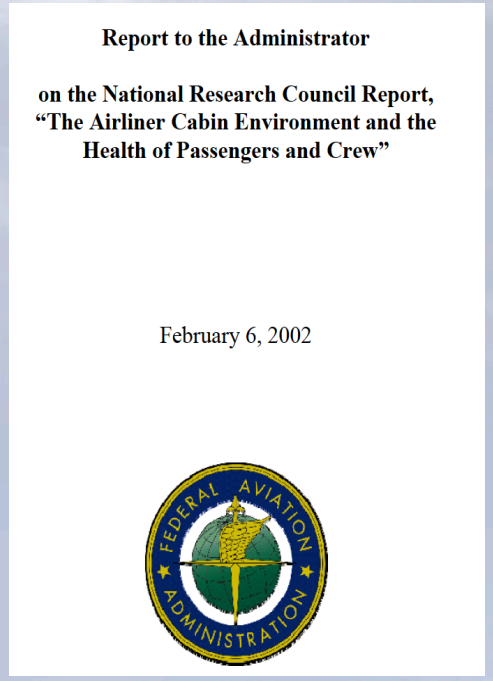


The National Academies of | SCIENCES ENGINEERING MEDICINE

- NRC report acknowledges that no measuring data had ever been published from an actual contaminated air event.
- Swab samples should be carried out after a suspected contaminated air event.
- Investigate need for filters, CO detectors
- FAA does not collect health effects data

Oil / Hydraulic fluid exposures - moderate concern

FAA - 2002



Report to the Administrator

on the National Research Council Report, "The Airliner Cabin Environment and the Health of Passengers and Crew"

February 6, 2002

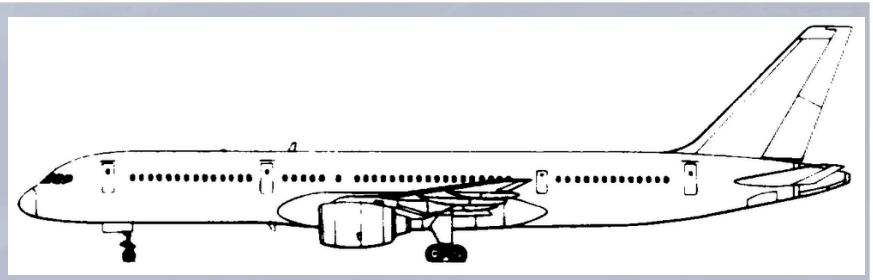
FAA rulemaking may not have kept pace with public expectation and concern about air quality and does not afford explicit protection from particulate matter and other chemical and biological hazards.

Will set up review of air quality standards **X**

Draft *Recommendation 1- Air Quality and Ventilation*

Rationale: No present airplane design fulfills the intent of 25.831 because no airplane design incorporates an air contaminant monitoring system to ensure that the air provided to the occupants is free of hazardous contaminants.

2003



A survey of health symptoms in BALPA Boeing 757 pilots

S MICHAELIS

flying
, Boeing 757 and Airbus
A320. Six hundred questionnaires were
sent out to members, and 106 pilots
responded. Survey respondents were
predominantly male (104/106) and many
had extensive flying experience. With
regard to leak events (that is, leaks of
engine oil and hydraulic fluids into the
aircraft), 93/106 reported that they had
been involved in at least one. The total
number of incidents reported was
estimated to be 1,674+, with all but seven
occurring on the B757. Following exposure
to the contaminated air, high rates of
symptoms were reported by the pilots,
including: irritation of the eyes, nose and
throat; headaches, light-headedness and
dizziness; fatigue, weakness and a
decrease in performance; a general
increase in feeling unwell; concentration
difficulties and confusion; diarrhoea;
nausea, vomiting and gastrointestinal
problems; numbness (head, limbs, line
fingers); short-term

Safety Regulation Group

CAA PAPER 2004/04

Cabin Air Quality

2004

UK CAA Report

Civil Aviation Authority

to identify any products that could be liberated in the aircraft air conditioning system and delivered into the cabin and flight deck. The conclusions from Phase 2 were that the ducts were contaminated with a carbonaceous material containing chemicals entirely consistent with the pyrolysis products of aircraft engine oil. Short chain organic acids were present and the odour of the duct was similar to pentanoic acid, one of the acids that can produce irritant effects. Basic toxicology surmises that increase in exposure time or concentration of an irritant can cause an increase in the severity of symptoms and this fits the variable nature of the reported incidents as they have affected individual aircrew. Some additional compounds were found in [illegible] TOCP), but toxicological review of these previously [illegible] are most unlikely to be present in sufficient concentration to have a physiological effect and, in any case,

Entirely consistent with the pyrolised products of engine oil.

2005 2 Day Conference - London



GCAQE
Global Cabin Air Quality Executive

Conference Conclusions

- There is a workplace problem – acute & chronic health effects
- Workplace - cabin environment
- Significant flight safety issues
- Passengers may be at (health) risk

GCAQE

VIDEO OPTION

2005 - Zurich

Investigation Report

by the Aircraft Accident

Investigation Bureau

concerning the serious incident

to aircraft AVRO 146-RJ 100, HB-IXN

operated by Swiss International Air Lines Ltd.



incident is attributable to the fact that on approach
d with fumes which caused a toxic effect, leading to a
e copilot.

es were caused by an oil leak as a result of a bearin
indicators for impending bearing damage were not
incident.

Toxic Effect

2005



1 Dec 2005 : Column WA58

Aviation Health: Contaminated Air

The Countess of Mar asked Her Majesty's Government:

> Further to the Written Answer by the Lord Davies of Oldham on 19 October (*WA 126*), how many air quality monitoring exercises were carried out during contaminated air events in commercial jet aircraft; and on what occasions. [HL2312]

Lord Davies of Oldham: There is no requirement for air quality monitoring exercises to be carried out during contaminated air events in aircraft, and there is no record of any such measurements in the public domain. Air quality measurements are normally only made as part of the initial certification of each aircraft type.

House of Lords - 2007



HOUSE OF LORDS

Science and Technology Committee

1st Report of Session 2007–08

Air Travel and Health: an Update

Report with Evidence

Recommend:

- Awareness campaign - reporting **X**
- Research to identify substances in fume events
- Epidemiological study - pilots **X**
- Government, manufacturers, regulators & airlines take effective action to prevent exposure to oil and hydraulic fluids.
- Medical protocol **X**

2007

ASHRAE Standard 161P

ASHRAE® Standard

Standard 161, *Air Quality Within Commercial Aircraft*

1. PURPOSE

This Standard defines the requirements for air quality in air-carrier aircraft and specifies methods for measurement and testing in order to establish compliance with the standard.

2. SCOPE

2.1 This standard applies to commercial passenger air-carrier aircraft carrying 20 or more passengers and certified under Title 14 CFR Part 25.

2.2 This standard considers chemical, physical, and biological contaminants as well as, but not limited to, factors such as moisture, temperature and pressure that may affect air quality.

2.3 Because this standard cannot take into account every variable, especially those relating to safe operation of the aircraft, the diversity of sources and types of contaminants in aircraft cabin air, and the range of susceptibility in the population, compliance with this standard will not necessarily ensure acceptable aircraft cabin air quality for everyone.

AMERICAN SOCIETY OF HEATING, REFRIGERATING
AND AIR-CONDITIONING ENGINEERS, INC.
1791 Tullie Circle, NE Atlanta GA 30329-2305

2007

AGREEMENT

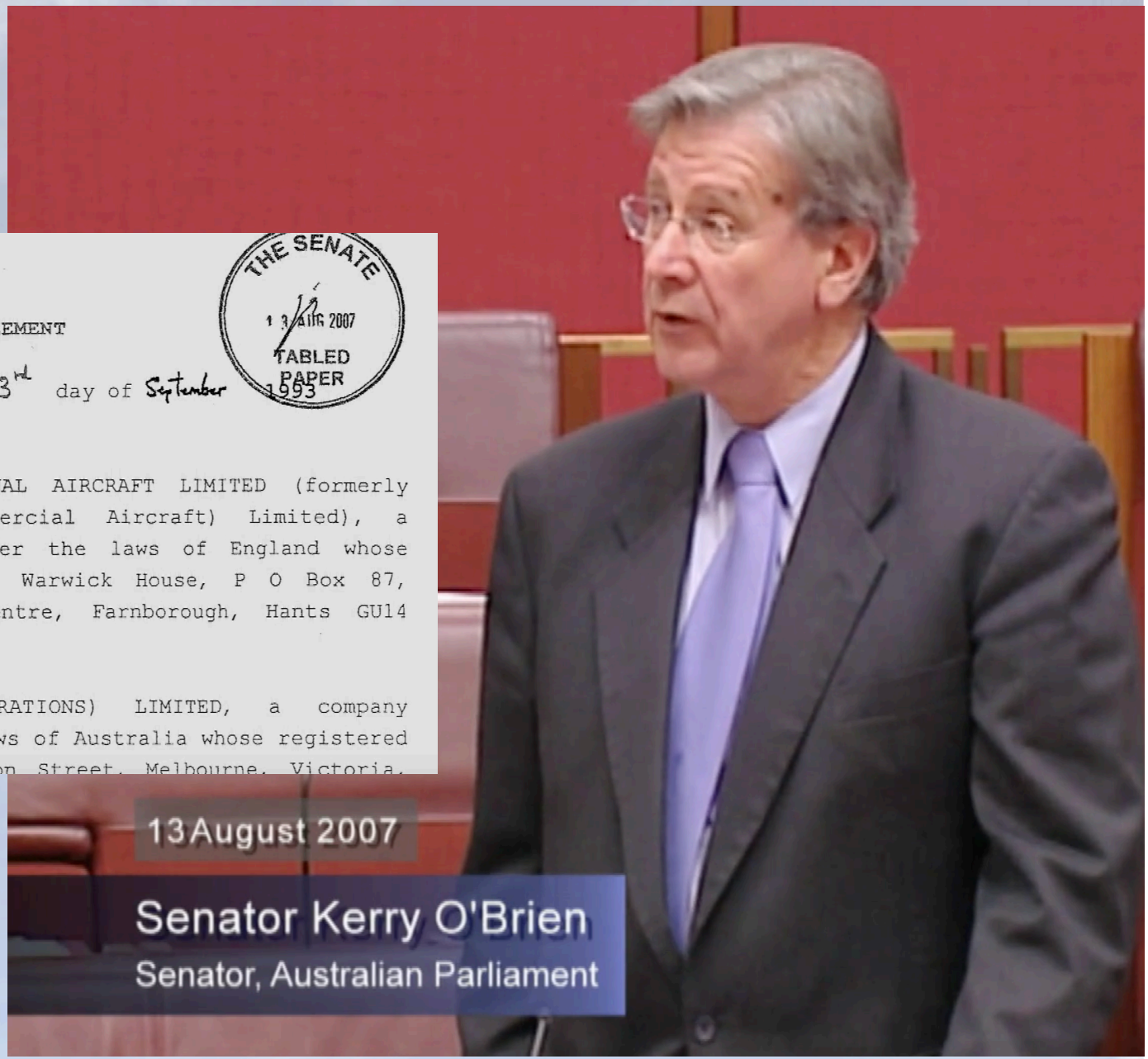
THIS AGREEMENT is made on the 3rd day of September 1993

THE SENATE
13 AUG 2007
TABLED PAPER

BETWEEN:

(1) BRITISH AEROSPACE REGIONAL AIRCRAFT LIMITED (formerly British Aerospace (Commercial Aircraft) Limited), a company incorporated under the laws of England whose registered office is at Warwick House, P O Box 87, Farnborough Aerospace Centre, Farnborough, Hants GU14 6YU, England ("BAe"); and

(2) EASTWEST AIRLINES (OPERATIONS) LIMITED, a company incorporated under the laws of Australia whose registered office is at 501 Swanston Street, Melbourne, Victoria,



…..in respect of oil or other fumes adversely affecting the cabin environment.

GCAQE
Global Cabin Air Quality Executive

2007

Safety Recommendations

Air Accidents Investigation Branch

Safety Recommendation 2007-002

It is recommended that the EASA consider requiring, for all large aeroplanes operating for the purposes of commercial air transport, a system to enable the flight crew to identify rapidly the source of smoke by providing a flight deck warning of smoke or oil mist in the air delivered from each air conditioning unit.

Safety Recommendation 2007-003

It is recommended that the FAA consider requiring, for all large aeroplanes operating for the purposes of commercial air transport, a system to enable the flight crew to identify rapidly the source of smoke by providing a flight deck warning of smoke or oil mist in the air delivered from each air conditioning unit.

GCAQE
Global Cabin Air Quality Executive

2009 FAA funded medical protocol

EXPOSURE TO AIRCRAFT BLEED AIR CONTAMINANTS AMONG AIRLINE WORKERS

A GUIDE FOR HEALTH CARE PROVIDERS

April 2009

Robert Harrison, MD, MPH[1]
Judith Murawski, MSc, CIH[2]
Eileen McNeely, PhD[3]
Judie Guerriero, RN, MPH[1]
Donald Milton, MD, DrPh[4]

[1]University of California, San Francisco
[2]Association of Flight Attendants-CWA, AFL-CIO
[3]Harvard School of Public Health
[4]University of Massachusetts Lowell

Funding for this project has been provided by the Federal Aviation Administration Office of Aviation Medicine and is part of a collaborative project between the Occupational Health Research Consortium in Aviation (OHRCA) and the Airliner Cabin Environment research (ACER) Center of Excellence. This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents thereof.

Federal Aviation Administration

2009 Boeing 787 - 1st Flight



Boeing stated to the UK House of Lords in 2007 that the 787 would have a no-bleed architecture that would eliminate “the risk of engine oil decomposition products being introduced in the cabin supply air in the rare event of a failed seal”.

European Aviation Safety Agency

SUPPLEMENTAL TYPE CERTIFICATE

10030229

This Supplemental Type Certificate is issued by EASA, acting in accordance with Regulation (EC) No. 216/2008 on behalf of the European Community, its Member States and of the European third countries that participate in the activities of EASA under Article 66 of that Regulation and in accordance with Commission Regulation (EC) No. 1702/2003 to

STC TWENTY ONE LIMITED
The Waldorf Centre
1290 London Road
ALVASTON, DERBY
DE24 8QP
UNITED KINGDOM

and certifies that the change in the type design for the product listed below with the limitations and conditions specified meets the applicable Type Certification Basis and environmental protection requirements when operated within the conditions and limitations specified below:

Original Product TC Number: **FAA TCDS A2NM**
TC Holder: **BOEING**
Model: **B757-200/ -300**

EASA Certification Basis:
The Certification Basis for the original product and the following additional or alternative airworthiness requirements are applicable to this certificate
As per FAA TCDS A2NM and as modified by CRI D-01 and CRI H-01
The requirements for environmental protection and the associated certificated noise and/ or emissions levels of the original product are unchanged and remain applicable to this approval

Description of Design Change:
Introduction of Air Conditioning Filter

Associated Technical Documentation:
STC 21 Compliance Record, S21.COMP-0694, Issue 1, 03/06/2010
STC 21 Master Document List, S21.MDL-0694, Issue 1, 03/06/2010
or later revisions of the above listed documents approved by EASA

See Continuation Sheet(s)

For the European Aviation Safety Agency,

Date of issue: 04.06.2010

Henry WILDEGANS
Project Certification Manager
Large Aeroplanes

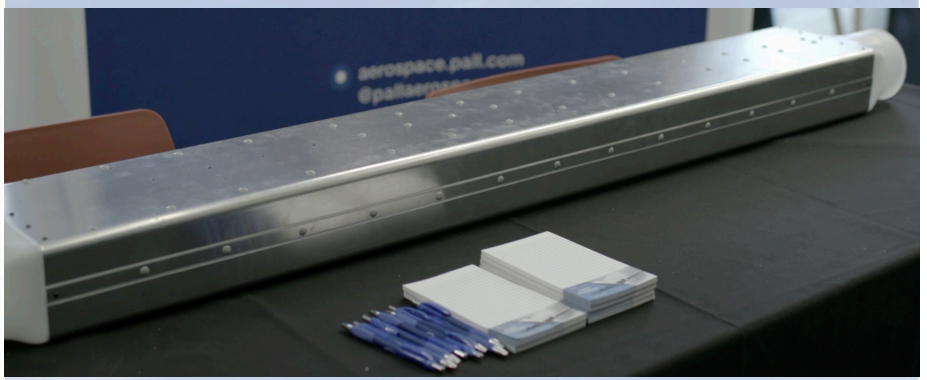
Note:
The following numbers are listed on the certificate:
EASA current Project Number: 0010001189-001
EASA old Project Number: P-EASA.A.S.03972
SUPPLEMENTAL TYPE CERTIFICATE - 10030229 - STC TWENTY ONE LIMITED

2010

Boeing 757

Cockpit Filter Unit (CFU)





GCAQE
Global Cabin Air Quality Executive

3 September 2010

Joanne Turner wins her long fight for justice in the High Court of Australia after 18 years of legal action.



"The plaintiff was exposed to pyrolysed effects of Mobil Jet Oil II on 4 March 1992"

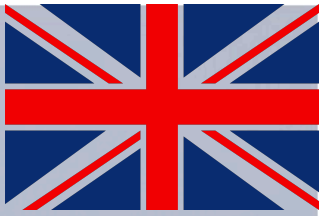
and

"that pyrolysed effects of Mobil Jet Oil II are harmful to the lungs."





Cranfield - 2011



IEH Institute of Environment and Health

Cranfield UNIVERSITY

Aircraft Cabin Air Sampling Study; Part 1 of the Final Report

TCP found in 25% of flights

TBP found in 73% of flights

No fume events occurred that triggered the protocols for formal reporting of incidents

No evidence for target pollutants occurring in the cabin air at levels exceeding available health and safety standards and guidelines.

ExxonMobil - 2013

ExxonMobil Fuels, Lubricants & Specialties Marketing Company
3225 Gallows Road
Fairfax, VA 22037
United States of America

ExxonMobil Aviation

Mr. Tobias Ellwood MP
The House of Commons
London SW1A 0AA
United Kingdom

May 24th 2013

Dear Mr. Ellwood,

No inhalation studies

OSHA and ACGIH are two organizations who establish exposure limits for chemical substances in ambient conditions. However, to the best of my knowledge, neither of those organizations have addressed the decomposition product of synthetic jet engine oils.

Numerous studies have been conducted on jet engine oils containing TCP via the oral route of administration. These were thoroughly reviewed in the report commissioned by the UK Department of Transport which is referenced above. ExxonMobil has conducted a

2014 Farnborough Air Show



"...and you don't have any problem with contaminated air, that's absurd."

GCAQE
Global Cabin Air Quality Executive

IATA - 2015

IATA Guidance for airline health and safety staff on the medical response to Cabin Air Quality Events

(Smoke, Fumes/odours)

Figure 1 (below) documents a potential airline 'triage' process for an in-flight or acute post-flight assessment.

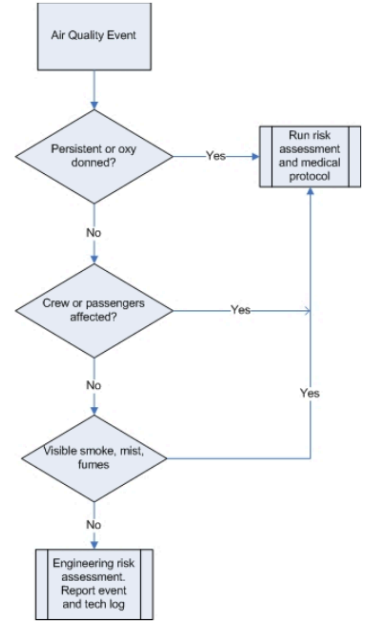


Figure 1. Flow Chart for In-flight or acute presentations of CAQE

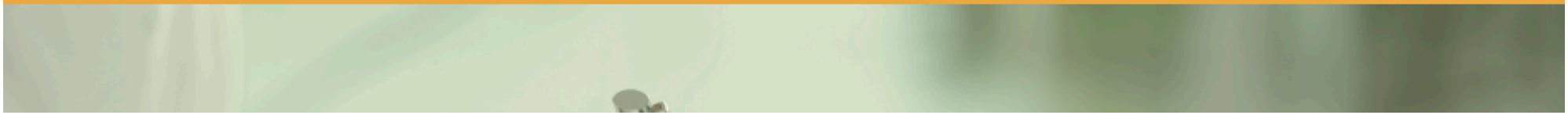
GCAQE
Global Cabin Air Quality Executive

2015

ICAO

Cir 344-AN/202

Guidelines on Education, Training and Reporting Practices related to Fume Events



Chapter 1

INTRODUCTION

1.1 BACKGROUND

1.1.1 There are various types of fumes, smoke, haze, and mist that may contaminate the cabin and flight deck air supply system. The outside air may be contaminated with engine oil, hydraulic fluid, engine exhaust, ground service vehicle exhaust, fuel, de-icing fluid, or ozone. The recirculation fans are another potential source of contaminated air. Also, electrical systems

Appendix 1 to Chapter 4

STANDARDIZED SMOKE/FUMES REPORTING FORM

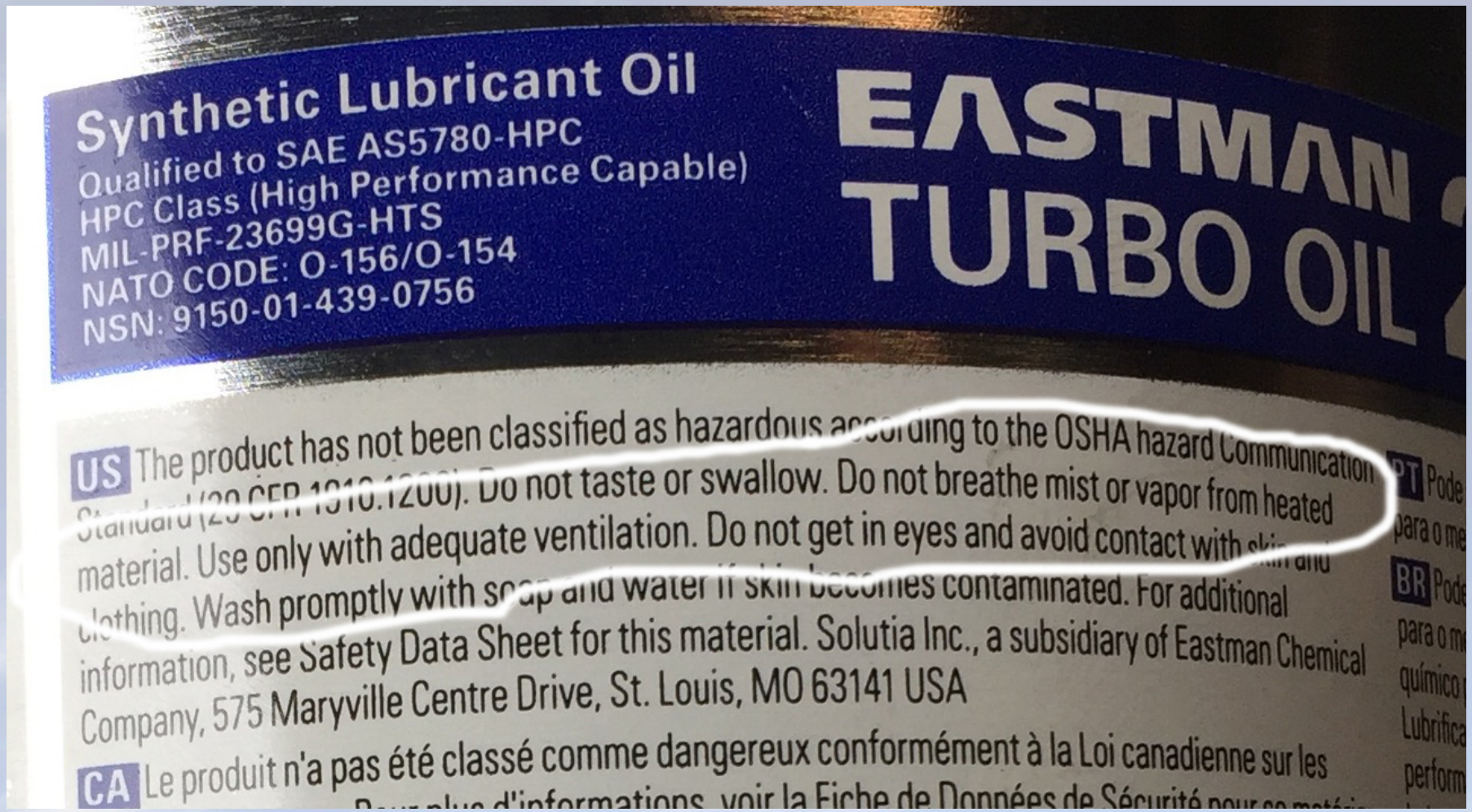
SMOKE/FUMES REPORTING FORM

SECTION 1: FLIGHT AND REPORTER DETAILS

Note: For each question, check all that apply. If one answer is dominant for a given question, write a ✈ next to that item.

AC number: _____	Flight date (DD/MM/YYYY): _____	**Form completed by:**
AC type: _____	Reporter name: _____	☐ Flight crew ☐ Cabin crew ☐ Maintenance ☐ Other
Tech log # (if known): _____	Employee no.: _____	
Departure stn.: _____	Email: _____	**PIC signature:** _____ (operator discretion)
Arrival stn.: _____	Phone: _____	
Phase(s) of	**Estimated duration of incident:**	**Recent aircraft service history:**

Eastman – 2016 Circa ???



2017

AGENDA DAY 1

Subject to change

08:00-08:50 REGISTRATION AND REFRESHMENTS

SESSION ONE:

09:00-09:03 CONFERENCE INTRODUCTION
Captain David Hoy Conference Host

09:04-09:20 OPENING KEYNOTE SPEECH
Countess of Mar Co-Patron of the GCAQE and guest **Captain Nils Gomer**

09:21-09:40 ORIGINS OF CONTAMINATED AIR
Captain Tristan Loraine BCAi
GCAQE Spokesperson

09:41-09:57 THE JET ENGINE INTERNAL AIR SYSTEM
Professor Peter Childs
Head of the School of Design Engineering, Imperial College London

09:58-10:25 MECHANISMS OF OIL LEAKAGE INTO THE CABIN AIR SUPPLY AND REGULATORY IMPLICATIONS
Dr. Susan Michaelis PhD
University of Stirling/Consultant
Mr. John Morton
Chairman European Seals Association

10:26-10:45 AIRCRAFT CABIN AIR AND ENGINE OIL - AN ENGINEERING VIEW
Professor Dr.-Ing. Dieter Scholz MSME
Aircraft Design and Systems Group (AERO) - Hamburg University of Applied Sciences

10:46-10:59 Q&A

11:00-11:25 REFRESHMENTS AND NETWORKING

SESSION TWO:

11:30-11:39 FLIGHT SAFETY: A PERSONAL PERSPECTIVE (FILM)
Captain Ray Cockerton

11:40-12:00 ICAO GUIDELINES ON EDUCATION, TRAINING AND REPORTING OF FUME EVENTS
Dr. Antti Tuori IFALPA - HUPER Vice chair, A320 CDR, M.D, PhD

12:01-12:21 EASA AND FAA KEY FINDINGS
Captain Max Thomson GCAQE Boardmember **Mr. Jordan Bray-Stone** CUPE & GCAQE Boardmember

12:22-12:42 CABIN AIR QUALITY: THE INTERNATIONAL PERSPECTIVE
Mr. Arie Adriaensen
Vereinigung Cockpit/GCAQE

12:43-12:46 GCARS GLOBAL CABIN AIR REPORTING SYSTEM (FILM)
GCAQE

12:47-12:59 Q&A

13:00-13:50 BUFFET LUNCH AND NETWORKING

SESSION THREE:

14:00-14:15 HAIR ANALYSIS, AN INNOVATIVE BIO-MONITORING TOOL TO ASSESS TRI-CRESYL-PHOSPHATE (TCP)
Dr. Vincent Peynet PhD Directeur, Institut de Recherche et d'Expertise Scientifique - IRES

14:16-14:33 A CAPTAIN AND CABIN CREW PERSPECTIVE
Ms. Deanne DeWitt Crew

AGENDA DAY 2

08:00-08:50 REGISTRATION AND REFRESHMENTS

SESSION FIVE:

09:00-09:01 DAY TWO INTRODUCTIONS
Mr. Daniel Tandoi GCAQE Chairman

09:02-09:21 A WIN-WIN-WIN PATH FOR FLIGHT SAFETY, HEALTH AND CORPORATE PROFITS
Professor Colin Soskolne (Keynote Speaker) Dept of Public Health Sciences - Collegium Ramazzini and University of Alberta

09:22-09:31 THE LAST 18 YEARS (FILM)
Senator John Woodley GCAQE Co-Patron

09:32-09:52 INSTALLATION AND DATA ACQUISITION FROM A REAL TIME AIR QUALITY SENSOR (RTAQS) MONITORING PILOT BREATHING AIR
Mr Grant M. Slusher, MS Research Scientist, 711th Human Performance Wing (HPW) of the USAF: (WPAFB)

09:53-10:16 CLASSICAL 'ONE CHEMICAL AT A TIME' TOXICOLOGY CANNOT ADDRESS THE CABIN AIR QUALITY PROBLEM
Professor Vyvyan Howard Professor of Pathology (toxicology) - University of Ulster

10:17-10:41 ORGANOPHOSPHATE-BASED CHEMICALS, AXONAL TRANSPORT AND COGNITIVE DYSFUNCTION
Dr Alvin V. Terry Jr., Ph.D Chairman, Dept of Pharmacology & Toxicology - Augusta University

10:42-10:59 Q&A

11:00-11:25 REFRESHMENTS AND NETWORKING

SESSION SIX:

11:30-11:53 LUBRICANT AND LUBRICANT ADDITIVE DEGRADATION: IMPLICATIONS FOR CABIN AIR QUALITY
Dr David W. Johnson - Ph.D
Chairperson, Dept of Chemistry, University of Dayton

11:54-12:17 REACH SUBSTANCE EVALUATION OF TRICRESYL PHOSPHATE (TCP)
Ms Petra van Kesteren National Institute for Public Health and the Environment (RIVM), MSc, The Netherlands

12:18-12:42 TCP MEASUREMENT METHODS USED TO IDENTIFY FLIGHT CREW AND PASSENGER EXPOSURE
Professor Chris van Netten
Environmental Toxicology (Emeritus) - University of British Columbia

12:43-12:59 Q&A

13:00-13:50 BUFFET LUNCH AND NETWORKING

SESSION SEVEN:

14:00-14:24 MIND THE GAP? FALLING BETWEEN AVIATION AND OCCUPATIONAL HEALTH SAFETY REGULATIONS, HEALTH AND SAFETY MANAGEMENT AND GOOD PRACTICE IN CONTROLLING CABIN AIR QUALITY
Professor Andrew Watterson Director of Centre for Public Health and Population Health Research - University of Stirling

14:25-14:47 BA286 DIVERSION OCTOBER 2016 A CONSULTANT'S PERSPECTIVE
Dr. Susan Michaelis, PhD
University of Stirling/Consultant

14:48:15:12 CONTAMINATED AIR: REAL TIME MONITORING
Mr. Chris Savage Vice President Technology, Pall Aerospace

15:13-15:29 Q&A

15:30-15:55 REFRESHMENTS AND NETWORKING

SESSION EIGHT:

16:00-16:02 FINAL SESSION INTRODUCTION
Captain David Hoy Conference Host

16:03-16:07 HARMFUL TO THE LUNGS (FILM) / EXTRACTS FROM THE DOCUMENTARY 'BROKEN WINGS'
Ms Joanne Turner Former Flight Attendant

16:08-16:28 MAKING THE CASE FOR TOXIC FUME MANAGEMENT
Mr. Cliff Edwards Aviation Risk and Hazard Management Consultant (retired), former Senior Advisor at Shell Aircraft Ltd

16:29-16:49 THE USE OF EXPOSURE STANDARDS IN AVIATION
Professor Andrew Watterson Director of Centre for Public Health and Population Health Research - University of Stirling

16:50-17:10 THE LAW UP IN THE AIR
Mr. Michael Rawlinson QC
Barrister - 12KBW / Kings Chambers

17:11-17:31 FROM ASSOCIATION TO CAUSATION: A BRADFORD HILL APPROACH TO AEROTOXIC SYNDROME
Mr. David Gee Visiting Fellow, Institute of Environment, Health and Societies, Brunel University

17:32-17:45 Q&A

17:46-17:59 CLOSING SPEECH
Mr. Keith Taylor MEP
Green MEP for SE England

GCAQE
Global Cabin Air Quality Executive



See website as well for full list of sponsors and supporters

IMPERIAL COLLEGE LONDON
SOUTH KENSINGTON

GCAQE

2018

Federal Aviation Administration

U.S. Department of Transportation
Federal Aviation Administration

SAFO

Safety Alert for Operators

SAFO 18003
DATE: 3/26/18

Flight Standards Service
Washington, DC

Subject: Procedures for Addressing Odors, Smoke and/or Fumes in Flight

Purpose: This SAFO serves to identify a need to enhance flight crew procedures that mitigate the risk to passengers and crew in the event of odors, smoke and/or fumes.

Background: Inflight odor, smoke and/or fume events can occur without overt visual and/or olfactory cues. To mitigate adverse health consequences to passengers and crew, prompt and decisive action is critical.

2019

AGENDA DAY 1

Subject to change

08:00-08:54 REGISTRATION AND REFRESHMENTS

SESSION ONE:

08:55-08:59 CONFERENCE INTRODUCTION
Conference Host

09:00-09:20 OPENING KEYNOTE SPEECH
Captain Tristan Loraine BCAi
GCAQE Spokesperson

09:21-09:41 DEALING WITH CABIN ODOR EVENTS
Ricardo Pavia
TAP Engineers

09:42-10:02 A COMMANDER'S PERSPECTIVE
Captain Janet Bevan
Captain Eric Baillet

10:03-10:17 A UNION PERSPECTIVE
Howard Beckett
Assistant General Secretary of Unite for Legal and Politics

10:18-10:29 Q&A

10:30-10:59 REFRESHMENTS AND NETWORKING

SESSION TWO:

11:00-11:08 CABIN AIR QUALITY AN FAA OVERVIEW
Short Film

11:09-11:29 IFALPA POSITION ON CABIN FUMES
Dr. Antti Tuori IFALPA - HUPER Vice chair, A320 CDR, M.D, PhD

11:30-11:50 FLIGHT CREW RELATED ISSUES
Gitte Furdal Damm
Human Factors Consultant

11:51-12:11 A BRIEF BACKGROUND - AN AIR ACCIDENT INVESTIGATOR'S PERSPECTIVE
Tony Cable
Aircraft Accident Investigation Consultant (AAIB - retired)

12:12-12:32 CONTAMIANTED AIR: A FLIGHT SAFETY ISSUE.
Captain Nick McHugh
GCAQE Board Member

12:33-12:59 Q&A

13:00-13:59 REFRESHMENTS AND NETWORKING

SESSION THREE:

14:00-14:23 CABIN AIR SAMPLING OF ORGANOPHOSPHATES DURING FUME EVENTS IN AUSTRALIA.
Marcus Diamond
Australian Federation of Air Pilots

14:24-14:47 BLEED AIR CONTAMINATION DETECTION

AGENDA DAY 2

08:00-08:54 REGISTRATION AND REFRESHMENTS

SESSION FIVE:

08:55-08:59 CONFERENCE INTRODUCTION

09:00-09:24 THE TRIUMPH OF DOUBT: DARK MONEY AND THE SCIENCE OF DECEPTION
Professor David Michaels PhD, MPH
Milken Institute School of Public Health of George Washington University

09:25-09:48 THE REGULATORY IMPLICATIONS OF BLEED AIR SUPPLY CONTAMINATION
Dr. Susan Michaelis PhD, ATPL
University of Stirling

09:49-10:09 CABIN AIR CONTAMINATION - A SUMMARY OF ENGINEERING ARGUMENTS
Professor Dr.-Ing. Dieter Scholz MSME
Aircraft Design and Systems Group (AERO) - Hamburg University of Applied Sciences

10:10-10:25 A GPS PERSPECTIVE ON FUME EVENTS OVER 20 YEARS.
Dr. Moira Somers MD General Practitioner

10:26-10:40 Q&A

10:41-11:09 REFRESHMENTS AND NETWORKING

SESSION SIX:

11:10-11:30 OIL FUME EVENTS: HOW OFTEN?
Judith Anderson
MSc CIH – Industrial Hygienist, Association of Flight Attendants - CWA

11:31-11:51 AN APPROCAH TO THE INVESTIGATION OF SYMPTOMATIC PERSONS AFTER EXPOSURE TO AIRCRAFT FUME EVENTS
Dr. Jonathan Burdon
Consultant Respiratory Physician

11:52-12:12 LEGAL SUMMARY
Judy Cullinane
Aviation Legal Consultant

12:13-12:33 OCCUPATIONAL HEALTH PROBLEMS OF FLIGHT ATTENDANTS
James E. Cone
MD, Adjunct Assistant Professor

12:34-12:59 Q&A

13:00-13:59 REFRESHMENTS AND NETWORKING

SESSION SEVEN:

14:00-14:25 DEOXOTM OZONE AND OZONE/VOC CONVERTERS: ESSENTIAL FOR CABIN CLEAN AIR
Victor Leung
Global Marketing Manager, Clean Air BASF

14:26-15:01 COLLABORATIVE DEVELOPMENT OF AN AIRCRAFT FRESH AIR FILTRATION SYSTEM
Dr. David Stein
VP, Aerospace Global Strategic Marketing, Pall Corporation

15:02-15:29 Q&A

15:30-15:59 REFRESHMENTS AND NETWORKING

SESSION EIGHT:

16:00-16:20 MAKING THE SAFETY CASE FOR AIRCRAFT OPERATORS (FUME RISK IN THE CABIN/COCKPIT)
Cliff Edwards
Aviation Risk Management Consultant (Retd)

16:21-16:41 SUSPECTED AIR QUALITY PROBLEMS ON BOARD - EXPERIENCES & ACTIONS
Richard Hansen
Technical Safety Officer
Safety Office - Icelandair

16:42-17:02 CABIN CREW AND TOXIC FUMES
Lori Bassani
President of APFA

17:03-17:18 CABIN CREW PERSPECTIVE
Melissa Dray
Former crew member

17:19-17:34 CLOSING SPEECH
Countess of Mar
Member of the House of Lords and GCAQE Co-Patron

GCAQE
Global Cabin Air Quality Executive

AIRCRAFT CABIN AIR
International Conference 2019

IMPERIAL COLLEGE LONDON
SOUTH KENSINGTON

INTERNATIONAL AEROSPACE CONFERENCE

AIRCRAFT CABIN AIR CONFERENCE

Flight Safety and Cabin Air Quality

2 Day Conference
17-18 SEPTEMBER 2019

aircraftcabinair.com

PALL Aerospace · AFAP · unite the UNION · GCAQE · BASF

See website for full list of sponsors and supporters

2019

https://gcars.app

GCARS

Global Cabin Air Reporting System

GCARS is a tool designed to help you easily report incidents of poor air quality/fumes to the Global Cabin Air Quality Executive.

REPORT AN INCIDENT

or

AMEND AN EXISTING REPORT

2020

BEFORE THE WORKERS' COMPENSATION BOARD

STATE OF OREGON

HEARINGS DIVISION

GLEN LASKEN
ATTORNEY AT LAW, P.C.
777 NW Wall Street, Suite 308
Bend, Oregon 97703
(541) 549-0644
1-(800)-896-6976 FAX (541) 549-0647

SISTERS
220 N. Pine Street

BEND
777 N.W. Wall Street, #308

July 14, 2020

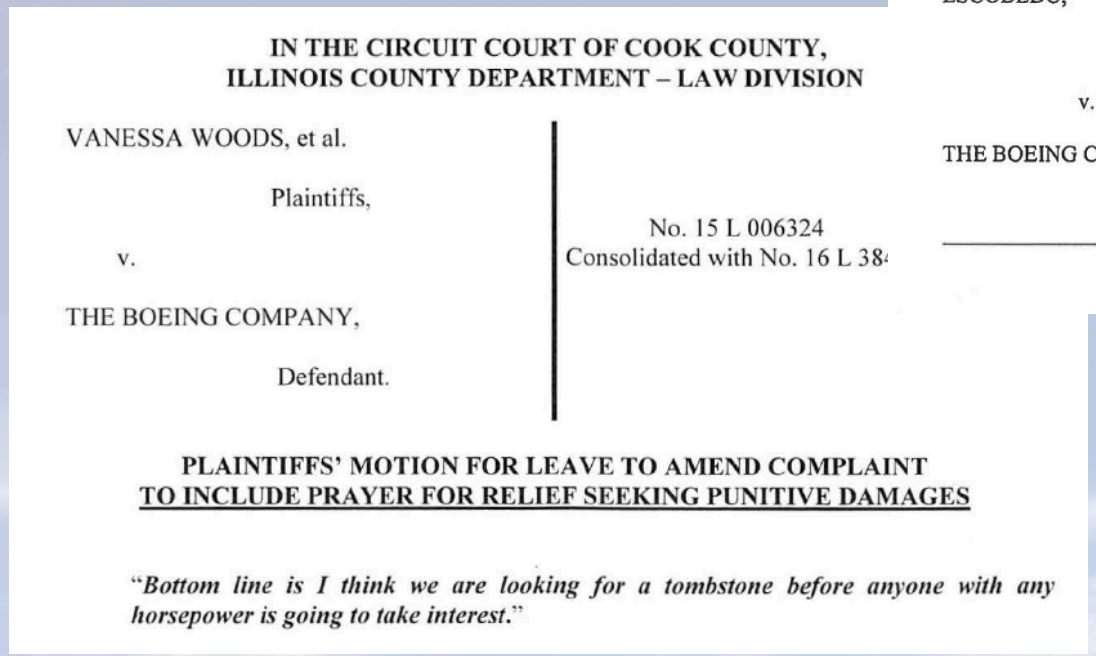
Judge Darren Otto
Workers' Compensation Board
Hearings Division
16760 SW Upper Boones Ferry Rd., Suite 220
Portland, OR 97224

RE: Claimant: Andrew K. Myers
WCB Nos.: 18-00006H; 18-04163; 19-00865; 19-01328; 19-01791; 19-02648
Claim No.: 555-232469
DOI: 1/21/17
Employer: JetBlue Airways, Corp.
D/Hearing: October 21, 2019; March 9, 2020

GCAQE
Global Cabin Air Quality Executive

Woods / Escabedo v Boeing - 2020

- Woods et al v The Boeing Company
- Escobedo v The Boeing Company



IN THE CIRCUIT COURT OF COOK COUNTY,
ILLINOIS COUNTY DEPARTMENT – LAW DIVISION

VANESSA WOODS, et al.

Plaintiffs,

v.

THE BOEING COMPANY,

Defendant.

No. 15 L 006324
Consolidated with No. 16 L 38

PLAINTIFFS' MOTION FOR LEAVE TO AMEND COMPLAINT TO INCLUDE PRAYER FOR RELIEF SEEKING PUNITIVE DAMAGES

"Bottom line is I think we are looking for a tombstone before anyone with any horsepower is going to take interest."



IN THE CIRCUIT COURT OF COOK COUNTY ILLINOIS
COUNTY DEPARTMENT, LAW DIVISION

VASHTI ESCOBEDO and RAY C. ESCOBEDO,

Plaintiffs,

v.

THE BOEING COMPANY,

Defendant.

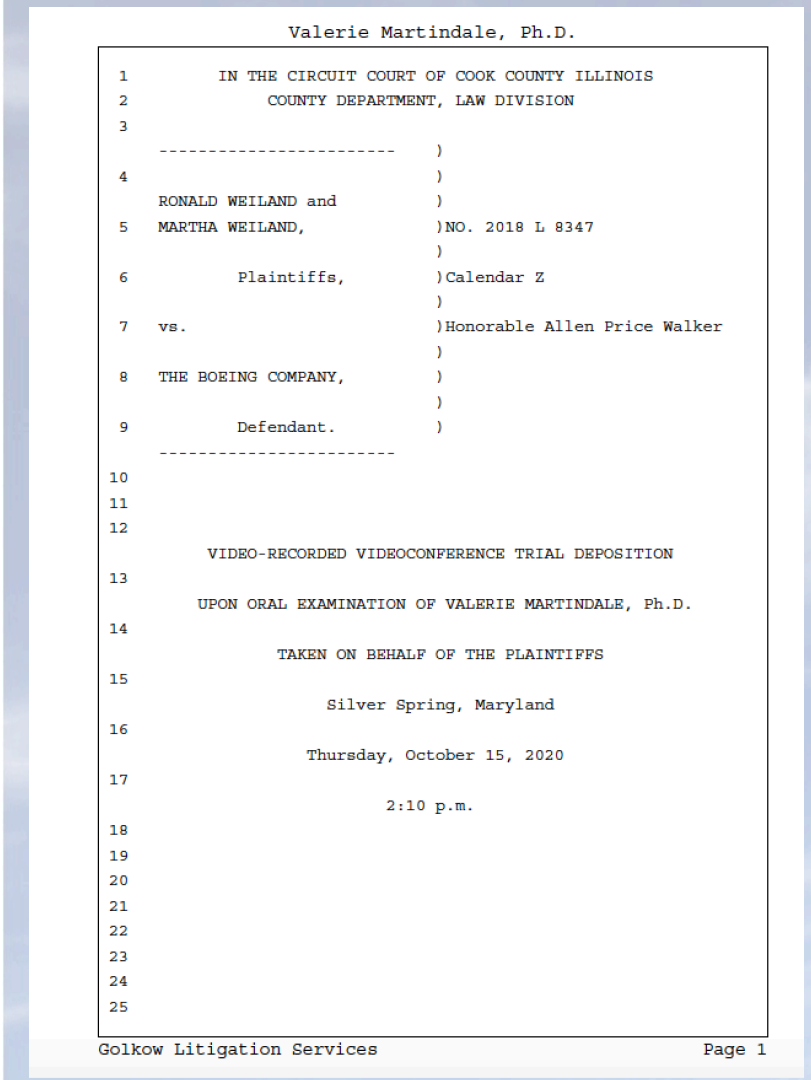
2016L003846
CALENDAR/ROOM H
TIME 00:00
PI Other

NO. _____

Plaintiffs Demand Trial by Jury

COMPLAINT

The Aerospace Medical Association (*AsMA*) – October 2020



Valerie Martindale, Ph.D.

IN THE CIRCUIT COURT OF COOK COUNTY ILLINOIS
COUNTY DEPARTMENT, LAW DIVISION

RONALD WEILAND and MARTHA WEILAND, Plaintiffs, vs. THE BOEING COMPANY, Defendant.

NO. 2018 L 8347
Calendar Z
Honorable Allen Price Walker

VIDEO-RECORDED VIDEOCONFERENCE TRIAL DEPOSITION

UPON ORAL EXAMINATION OF VALERIE MARTINDALE, Ph.D.

TAKEN ON BEHALF OF THE PLAINTIFFS

Silver Spring, Maryland

Thursday, October 15, 2020

2:10 p.m.

Golkow Litigation Services Page 1

Oral Examination of:

Valerie E. Martindale, PhD, CAsP, FAsMA

Past President of AsMA



198

Original research

AEROTOXIC SYNDROME: A NEW OCCUPATIONAL DISEASE?

Susan Michaelis[1], Jonathan Burdon[2], C. Vyvyan Howard[3]

[1] School of Health Sciences, University of Stirling, United Kingdom
[2] Consultant Respiratory Physician, Melbourne, Australia
[3] Centre for Molecular Biosciences, University of Ulster, United Kingdom

Corresponding author: Susan Michaelis (email: susan@susanmichaelis.com)

ABSTRACT

Background: Concerns related to adverse health effects experienced by aircrew exposed to aircraft contaminated air have been ongoing for over 6 decades. Unfiltered breathing air is supplied to the cabin via the engine compressor. The likelihood that oil leaking over the engine oil seals may enter the cabin air supply has prompted continuing debate about the hazards associated with exposure to neurotoxic substances and to the thermally degraded or pyrolysed mixture. In this study, we undertook an in-depth investigation of aircrew involved in suspected aircraft contaminated air events.

Methods: Two studies were conducted to review the circumstances and symptoms of a cohort of aircrew working in the pressurized air environment of aircraft. A table of effects was then used for categorizing symptoms and reviewing other sources of data related to aircraft fluids and selected other conditions.

Results: Both acute and chronic exposures to neurotoxic and a wide range of thermally degraded substances were confirmed, along with a clear pattern of acute and chronic adverse effects. The latter were supported by medical findings and diagnoses, notably involving the neurological, neurobehavioural and respiratory systems.

Conclusion: A clear cause and effect relationship has been identified linking the symptoms, diagnoses and findings to the occupational environment. Recognition of this new occupational disorder and a clear medical investigation protocol are urgently needed.

Keywords: AEROTOXIC SYNDROME, AEROTOXICITY, CABIN AIR CONTAMINATION, CABIN AIR QUALITY, JET ENGINE OILS, OIL FUMES, TCP

150 + research projects & initiatives (1950-2020)

> Problem still exists <

European Commission

MOBILITY AND TRANSPORT

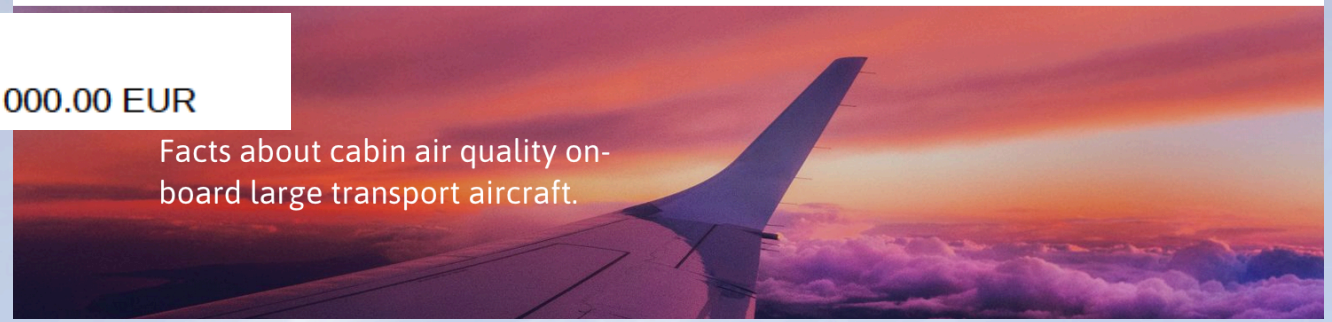
EASA European Aviation Safety Agency

II.1.5) **Estimated total value**

Value excluding VAT: 1 950 000.00 EUR

FACTS FRESHAIRCRAFT

HOME BACKGROUND WORK PROGRAMME THE PROJECT FAQ INTERVIEWS



FACTS - Study did not meet objectives - No final report available as of March 2021

~60 years from first flight to Mach 3 +



>>>>>>>>>



FAA aware of the issue for ~60 years

1966

DuFour, T.C.

Bleed Air Contamination in Military and Civil Aircraft,

Federal Aviation Administration Report

Project 66213140

(1966).

Still NO Solution

GCAQE

To Conclude - In summary

- Problem first known in early 1950s
- Over 150 pieces of research & other initiatives to date
- Acknowledged flight safety issue
- FAA and EASA failing to mitigate to flight safety problem or protect crew and public health
- Increasing legal actions
- Effective total cabin air filtration and onboard sensors needed to enhance flight safety and protect public health.

History of Contaminated Air From 1903 to Present

Questions and Answers

Captain Tristan Loraine

GCAQE Spokesperson

Aircraft Cabin Air International Conference 2021 (ACA 2021) – Proceedings

Conference: Online, 15-18 March 2021
Conference Director: Tristan Loraine
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Editors: Dieter Scholz, Susan Michaelis

Contaminated Air – The Perspective Of a Former Airline-Training Captain

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Abstract

A former airline-training captain reports on contaminated cabin air and its impact on the industry's reputation and pilots' health.

Keywords

cabin air, quality, contamination, medical issue, humility, safety, pilot

We are, currently, living in unprecedented times. Some would say it's the wrong time, to be raising awareness on the issue of contaminated cabin air. Many of our colleagues around the world, fearful of job losses, uncertainty and the ensuing professional and social disruption, caused by the SARS-CoV-2 virus, would say that there are more immediate and pressing concerns. Of course, these concerns are justified. However, flight safety does not sleep, and if anything, as an industry that prepares for return to work, we as crew members need to be more vigilant and self-aware than ever.

For all who have been affected or yet to be affected by the issue of contaminated cabin air, in looking at the Human Factors, we now need to introduce a little more humanity. We are not machines, and for the poets among you today, I would like to share with you some lines from Rudyard Kipling's wonderful poem, 'The Secret of the Machines' (Kipling 1941). Putting it in context, what follows is from the perspective of the machine as it speaks to the reader:

But remember, please, the Law by which we live,
We are not built to comprehend a lie,
We can neither love nor pity nor forgive.
If you make a slip in handling us you die,
Be humble, as you crawl beneath our rods.

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Review process: Editorial review. The corresponding author is marked with *.

In our industry of late, there has been a distinct lack of this humility, with the many regulatory and manufacturing failures and ensuing loss of life - Hard won reputations established over many decades thrashed in an instant, and for what gain? No effort or endeavour by all should be spared, in restoring what has been lost.

You may indeed ask: "What has any of this got to do with cabin air quality?" to which my reply is: "everything." For it is this very confidence which will be instrumental in restoring our industry's damaged reputation. We are assured by the regulators that 'the air quality on passenger jet aircraft, is similar to, or better than what is observed in normal indoor environments.' Yet, we know that is not the case. It is no longer acceptable to ignore the many recommendations and proposals to install effective monitoring and filtration equipment in aircraft cabins. Those familiar, doubtful refrains of "the science is unclear," or "the data inconclusive," or "more research is required" and "regulation is unjustified," are tiresome and frustrating. Further reading of interest can be found in Professor David Michaels book, 'The Triumph of Doubt' and brings us fresh hope for the future (Michaels 2020).

From those first trial-and-error flights at Kittyhawk, North Carolina, to the highly regulated training environments of today, the advances in these technologies and training were quite unimaginable. This marriage of training and technology has however, not always been a harmonious one. For many years, pilot training was focused on a set of repetitive tasks which had historically contributed to accidents or incidents. The many accidents and incidents that were put down to 'Pilot error' may in fact have had a more sinister cause. Contaminated air was quite simply not a consideration, albeit the industry was aware of a problem from the outset. The question was never asked "why did the pilot make the error?" rather than accepting it as the root cause. Instead of being the end of the investigation, it should in fact have been the start of another. Would the answer have been found in the air that was breathed onboard? Who knows!

We as pilots are a unique occupational group, in terms of the testing and checking that we go through annually, in order to keep our licenses. Often as pilots, our performances will vary from very good to mediocre, and occasionally to bad. In the past, I have seen less than optimal performance, from myself included, put down to tiredness, social or domestic distractions or some other cause. Never was the environment we worked in a consideration.

More worryingly however, is the fact that there may be pilots flying that have medical issues, which they may, or may not be aware of, and not captured at medical renewal. I know pilots who have gone on long term sickness, never to return. Pilots who know they are unwell are afraid to reach out, from fear of the unknown.

In 2006, University College London (UCL) conducted random tests on a group of 27 Airline Pilots. The report found that the tests where these pilots underperformed, mapped perfectly onto the areas they reported subjectively, and in the main showing reduced neurocognitive function. Worryingly, according to the report 'a large proportion of those pilots were still flying at the time.' (Mackenzie Ross 2009).

In 2013, ICAO & IATA produced guidance on evidence-based training - a pilot training concept that is centred around competency-based training principles (IATA 2013). Again, the evidence for this program came from the analysis of accident and incident data, analysed in such a way to identify the competencies a pilot requires to operate an aircraft safely and effectively in today's environments. There are a number of issues with the Learning and Development Sciences and the overload of instructors which are beyond the scope of this brief.

However, I can mention that some legacy issues may create an impediment to experienced pilots being able to change competencies and find a new way to work. Despite the paradigm shift in evidence-based training, it will be of little or no use if it fails to deliver change. Further reading for those interested, is written by Suzanne K. Kearns in her book, 'Competency Based Education in Aviation: Exploring alternative training pathways.' (Kearns 2016).

"Knowing thyself is the key to all wisdom." Be kind to yourself and consider the environment we work in. The time for procrastination has now passed. By working together, the aim is to find a solution and prolong our flying careers. As to whether or not contaminated air is a threat to flight safety, I will let you be the judge of that!

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About the Author

Captain Nicholas McHugh has been a professional pilot for over 40 years. He started his career in the military and has been privileged to fly a variety of aircraft starting with the BAC 1-11, Boeing 737, Boeing 757, Boeing 747 and Airbus A320. He was a training captain on the Boeing 737 and holds a 1st Class Honours Bachelor of Science Degree. He is a board member of the Global Cabin Air Quality Executive (GCAQE).

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AIRCRAFT CABIN AIR
International Conference 2021

Air Accident Bureau Incident Reports - Case Study Review

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Abstract

Purpose: The purpose of the work reviewed in this short paper was to evaluate some of the common aspects highlighted in bureau of air safety investigations related to aircraft air supply fume events.
Methodology: An aircraft incident investigation report by the UK based Air Accidents Investigation Branch (AAIB) was examined, involving fume events reported on the A320 group of aircraft. The aim was to align the report with the current understanding of the aircraft contaminated air supply issue. A brief review of a recent French Bureau d' Enquêtes et d'Analyses (BEA) report as well as a collation of key recommendations and findings by bureaus of air safety was also undertaken.
Findings: Fume events associated with the aircraft air supply are not uncommon. A review of 6 A320 family aircraft reporting fumes at various transient phases of flight, commonly described as a dirty sock type odour, reported that no fault could be found. While there are a number of common features identified with these events as well as fume events in general, the report identified a reluctance to directly address air supplies contaminated with oil leakage and an incomplete appreciation of the wider implications of such exposures.
Limitations: This review has not been afforded access to the complete files used in the investigations.
Practical Implications: This brief review has wide implications for all aircraft using bleed air for ventilation purposes.
Social Implications: The findings outlined in this brief review are relevant to all aircrew, passengers and the aviation industry.
Value and Originality: The value of this review has the potential to change the way the aviation industry supplies air to aircraft crew and passengers globally.

Keywords (ACA Component Head)

AIB report, fume event, oil fumes, impairment, flight safety

1 Introduction

Contaminated air events sourced to the aircraft air supply, commonly known as fume events (FE) are not uncommon. These date back to the 1950s, when synthetic jet engine oils were introduced to higher performing gas turbine en-

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Related presentation: https://doi.org/10.5281/zenodo.4730428
Review process: Editorial review. The corresponding author is marked with *.

gines. There have been increasing FE reports, particularly over the last few decades. More recently there have been many FEs reported on the A320 family of aircraft.

There have been an increasing number of Air Investigation Bureau (AIB) reports published in the last 2 decades related to aircraft contaminated supply air and FEs. These have varied from the more common brief reports to a number of very extensive reports. There are recurring themes identified in the finding and analysis, with some publishing recommendations that exhibit a common pattern.

Many of these reports identify that the FEs were non-visible, involved some degree of impairment, were transient in nature, with numerous other common features including that no fault was found (NFF) after maintenance investigations.

2 Methodology

The AAIB report into an Airbus A320-232 G-EUYB incident that took place in 2019 was reviewed to align common themes highlighted with the wider understanding involving the aircraft contaminated bleed air FEs (AAIB 2020). The AAIB report included the main FE as well as 5 other similar FEs in which no maintenance fault was identified. A summary of key findings and recommendations from various international AIBs will be provided along with a brief review of a recent BEA report involving a fume event on an A330.

3 Findings

Over 3100 smell, smoke or fume (SSF) events were reported to the aviation regulator (CAA) over the previous 5 years with 107 fume events reported to the AAIB during this same period. The operator of the incident flight had reported 536 SSF events to the regulator of which 398 occurred on the A320 series of aircraft. The operator recorded approximately 880 odour and FEs in the 12 months to March 2020.

Of the 6 FEs investigated some of the common features included 4 were described as sweaty socks, all involved fumes only without visible smoke or haze, 5 occurred during start up climb and or approach, with one occurring during the cruise only. 2 and 1 of the FE flights involved a FE prior and after the main FE respectively. Impairment involving the pilots and cabin crew occurred in 1 and 3 of the 6 FE flights respectively, with the first officer becoming incapacitated due to nausea and vomiting. No passengers reported adverse effects. Throat irritation was most commonly reported, along with a range of other irritant effects, gastrointestinal effects, dizziness and headaches. The captain and first officer involved in the main event were both involved in serious prior FE incidents 9 months and 7 weeks respectively prior to the main incident flight. In all cases no fault was said to have been found after maintenance investigations. However, in 1 case an engine was replaced, another was reported to have possibly been overfilled with oil on the previous flight, another was released for service after a FE on the previous flight. The aircraft in the main event was released for service after NFF, with 4 further FEs reported on the same aircraft. Several features involved the FEs commonly occurring at around 4000 feet on the approach and in the circuit before landing, FEs occurring during the climb after damp/rain conditions or being parked overnight. The fumes were mostly transient, of short duration and in 4 of the 6 flights the fumes appeared, disappeared and then reappeared at various phases of flight. Various other common features were noted as shown in **Figure 1**.

4 Discussion

Compressor generated pressurised air is used to seal the oil bearing chambers in aircraft as shown in **Figure 2**. The use of pressurised oil bearing seals provides the mechanism for low level oil leakage past the seals in normal flight (Michaelis 2018, Howard 2018). Breathing air in most aircraft is sourced from the compressor and therefore oil passing over the seals in the area of the compressor, has a path to enter the cabin air supply if leakage or emissions occur prior to the air off-take location (Howard 2018).

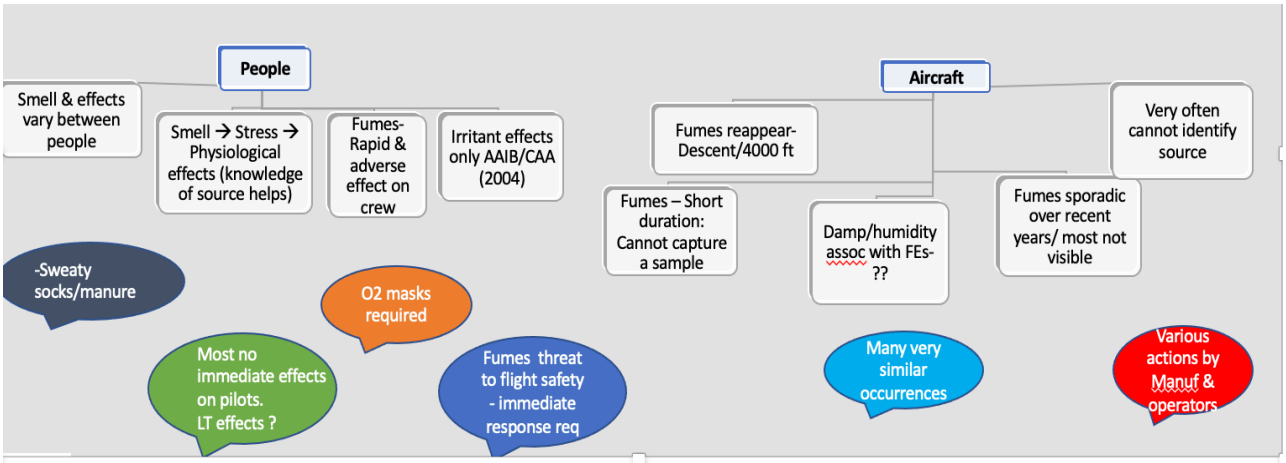


Figure 1 Features identified in the AAIB report (AAIB 2020).

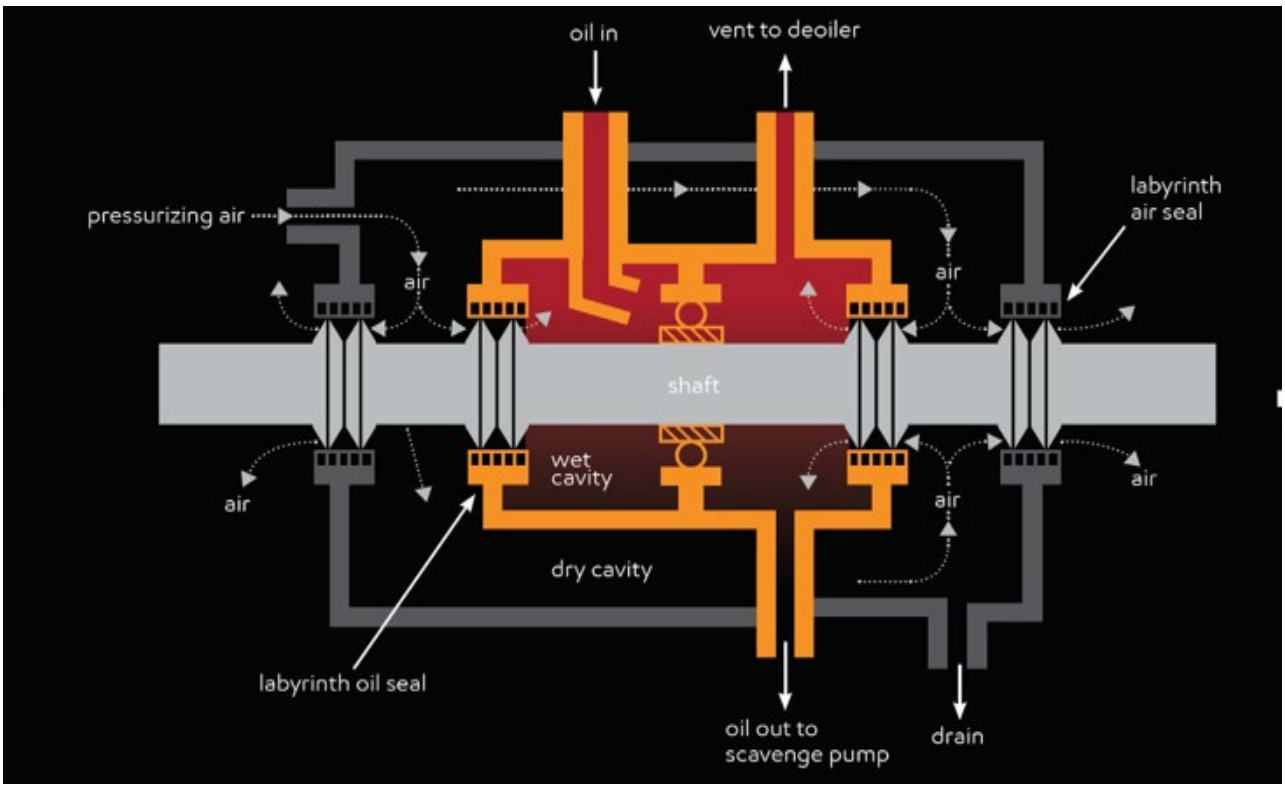


Figure 2 Typical oil bearing chamber (Exxon Mobil 2016).

A range of short and longer term health effects associated with contaminated aircraft air supplies and fume events include neurological, neurobehavioural, cardio, respiratory, gastrointestinal, irritant and other general effects (Michaelis 2017).

There are however various discrepancies in the AAIB overview of the common features of FEs that are shown in figure 1. Several examples include the following as shown in **Table 1**.

Table 1 Comparison of selected AAIB report findings and Case study review.

AAIB report (AAIB 2020)	**Air accident bureau incident reports - Case study review** (Michaelis 2021)
FEs associated with acute irritant effects.	Fumes associated with a range of toxic and hazardous effects (Michaelis 2017, ECHA 2008). A range of long-term effects are well documented (Winder 2005).
Most FEs do not have adverse effects on pilots.	Many reports identify adverse effects in pilots as well as cabin crew (Michaelis 2017, Michaelis 2010, BFU 2014).
FEs lead to a stressful situation which leads to physiological effects.	Checklists often address smoke only, education and training on FEs is lacking and a range of adverse effects are associated with the Fumes (BFU 2018, ICAO 2015, ECHA 2008, Michaelis 2017). Oil Material safety Data Sheets list a range of adverse effects.
FEs often have characteristic dirty sock/pungent smell	Oils and heat or moisture generate carboxylic acids, which have a known dirty sock odour (ASHRAE 2012, Johnson 2018).
Fumes are transient and therefore a sample cannot be captured.	There are no detection systems on board aircraft to capture FEs in real-time & there are a wide range of compounds associated with fumes captured in ad-hoc monitoring programs and pyrolysis studies (BFU 2014, Chen 2021).
Fumes often associated with humidity and various phases of flight.	Oil exposed to water (Hydrolysis) causes ester base stock to revert to carboxylic acids (ASHRAE 2012, Johnson 2018).
Very often cannot identify source for transient FEs.	Very little oil required to generate fumes & investigation techniques inadequate for the more common transient non-visible FEs as maintenance practices more appropriate for smoke events or failure conditions (Vera-Barcelo 2013, Howard 2018).
FEs occur more often during Start up, climb, descent/approach phase of flight.	Oil seals are less effective at these times with changing or reduced pressures over seals (Michaelis 2018).

Over the last 2 decades there have been an increasing number of AIB investigations and reports. While most are of a brief nature, some have been more extensive. There are an increasing number of important findings with over 50 recommendations made in 16 reports from 10 countries. These recommendations cover a variety of areas including airworthiness, maintenance and certification, protocols during and post FEs, international database, research addressing the oils, contaminants and effects on human health and detection and warning systems.

A French BEA investigation involving possible exhaust gases on lineup, oil leakage and partial incapacitation, reviewed a number of factors common to oil fumes exposures (BEA 2020). Several findings related to oil fumes were correctly outlined, however there were numerous areas showing an incomplete understanding of such exposures and oil leakage. This is a common deficiency in many AIB investigations, including both reports investigated in this review.

5 Summary and Conclusions

Despite there being a number of common features related to contaminated air and oil fume events as outlined in the AAIB report, there is no mention or a possible reluctance of oil fumes being mentioned as the likely cause of the transient FEs. The FEs are consistent with exposure to oil fumes. A lack of appreciation on how and why oil leakage and FEs occur is evident. There is a reliance on failure conditions leading to oil leakage, while leakage in normal operation is not given due consideration. Sensors and supply air filtration are clearly required. There is also an under appreciation of the health effects associated with such exposures and a clear need for a medical protocol to be utilized after FEs occur.

Abbreviations and Acronyms

AAIB Air Accidents Investigation Branch, UK
AIB Air Investigation Bureau
FE Fume Event
NFF No Fault Found
SSF Smell, Smoke or Fume

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Air Accident Bureau Incident Reports - Case Study Review

- Dr Susan Michaelis: PhD, MSc, ATPL
- Honorary Senior Research Fellow, University of Stirling
- Air Accident investigator (MSc, Cranfield, 2016)







2021 Aircraft Cabin Air Conference: 15 - 18 March 2021

UNIVERSITY of STIRLING

Reason for review - AAIB (2020)



Recurring themes:

1. Fume events not uncommon
2. No fault found is very common
3. Common features to fume events
4. Incomplete knowledge on topic

5. Main event:

- Airbus A320 – G-EUYB – Sept 2019: Zurich-LHR
- Strong acrid (sweaty socks/manure) fumes on approach to LHR
- Flight deck
- Both pilots adversely effected (Impairment & incapacitation)
- No fault found (NFF)
- Numerous other similar events: NFF

AAIB (2020) https://assets.publishing.service.gov.uk/media/5f16a2ab3a6f405c00b4456c/Airbus_A320-232_G-EUYB_09-20.pdf

Fume events not rare

Many similar events on Airbus A320 fleet (A318 /319/320/321)

- 37 fume reports – reported to AAIB in past 12 months: Various types (107 in 5 years)
- MORs: Smell, smoke or fumes: 674: 12 months; 3166: 5 years
- Operator of main event: 536 smell, smoke or fumes to CAA (398: A320 series)
- Operator: ~880 fume & odour events (Jan2019-Mar2020)

AAIB (2020) https://assets.publishing.service.gov.uk/media/5f16a2ab3a6f405c00b4456c/Airbus_A320-232_G-EUYB_09-20.pdf

6 ????s

Phase of flight	Climb & approach - 3 Cruise & ? - 1 Start up & approach - 1 ? & approach - 1
2 fume events during flight (ground/air)	6
FE before/(after) current FE flight	2 (1)
Aircraft parked overnight (rain drizzle/cloud)	1 (3) Main- parked overnight & rain
Smoke / (fumes)	0 (6)
Description of fumes	Sweaty socks – 4 Manure – 1 Wet laundry/moldy – 1 Plasticine – 1 Cheesy feet – 1 Acrid - 1
Location	Flight deck (FD) – 3 FD & cabin – 2 Cabin - 1

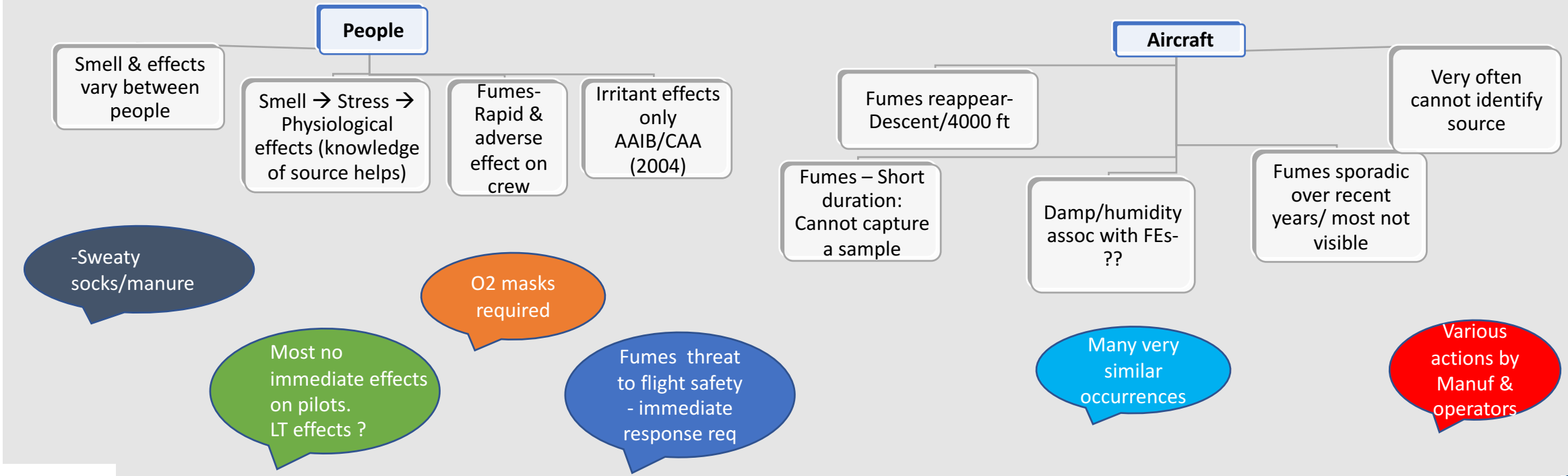
AAIB (2020) https://assets.publishing.service.gov.uk/media/5f16a2ab3a6f405c00b4456c/Airbus_A320-232_G-EUYB_09-20.pdf

Impairment – x flights out of 6	Pilots (1); Cabin crew (3); Pax (0)
Number of crew impaired in FE *incapacitated (nausea/vomiting)	Pilots (2*); Cabin crew (>1)
Description of effects * Pilots in main Zurich event	Tingling/scratchy*/burning*/dry/sore throat -5 Itchy skin*/eyes -2 Nausea* & vomiting* -1 Dizzy head/headache -2 Nasal congestion - 1
PAN / Pilots using O2 (*main event only*) / Checklist	5/4/6
Main event – Pilots Impaired /previous events	Capt - Geneva FE (descent) - 9 months before/hospitalization FO – Valencia Fumes & smoke serious incident- 7 weeks before
Continued flight after 1st FE on flight	5

UNIVERSITY of STIRLING

Source of FE (No fault found = NFF) Main event*	Event 1*: NFF + 4 further events (NFF) Event 2: Released for service after prior FE flight Event 3: No conclusive results /oil overfill on previous FE flight Event 4: Likely burnt pastry? Event 5: Engine replaced Event 6: ? All said to have no source/cause found
Fumes appear/disappear/reappear	4
FE: Descent cloud *	Descent/approach ~4000/5000ft: 3 Approach/circuit*: 1 Descent: 1
FE: Climb	Climb - parked overnight / rain: 1 Climb: 1 Climb: 1 – Damp/drizzle pre departure
Medical attention/ (Hospitalization)	4 / (2)
Passengers affected	0

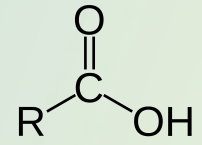
Points made in report



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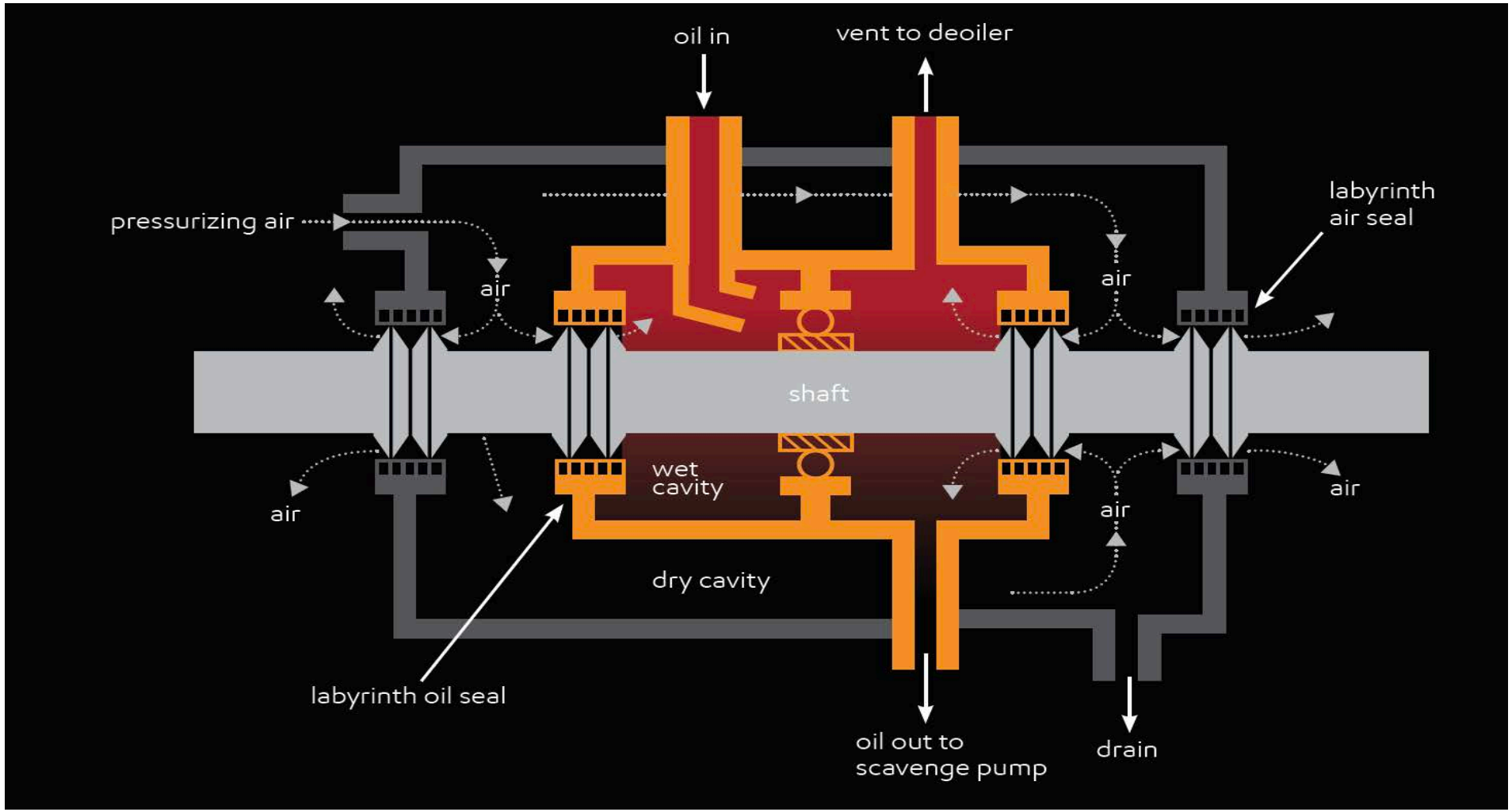
Factor	AAIB (2029)	Comment
Description	Dirty socks/ manure	Oils + heat or moisture > carboxylic acids (dirty socks) - Ester base stock of oil reverts back to carboxylic acids
Fumes	Not visible	ICAO (2015) – Fumes not usually accompanied by visible smoke or haze
Phase of flight	Start up, climb, descent/approach	Oil seals less effective at these times: > Changing or reduced pressures over seals
Cloud/humidity	Common factor	Hydrolysis: Water & oil → carboxylic acids (oil base stock)
Descent ~4000ft	Common	Low pressure over seals/ changing pressures
Transient Appear/reappear	Common	Most common See phase of flight > e.g. Start up, Taxi, T/O, climb & descent, approach
No fault found	All	• Very little oil required to create fume; • Investigative techniques inadequate for lower-level oil fume events; • Transient fumes usually not detectable • No sensors -





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Oil bearing chamber



https://www.exxonmobil.com/en/aviation/knowledge-library/resources/jet-engine-oil-system-2

World Health Organization
REGIONAL OFFICE FOR Europe

PUBLIC HEALTH PANORAMA VOLUME 3 | ISSUE 2 | JUNE 2017 | 141-356

2017

Original research

AEROTOXIC SYNDROME: A NEW OCCUPATIONAL DISEASE?

Susan Michaelis[1], Jonathan Burdon[2], C. Vyvyan Howard[3]

TABLE 1. STUDY B: KEY FINDINGS

CATEGORY	Column A
TYPE OF EVENT	Fumes x 12; Fumes & haze or smoke x 3
LOCATION	Flight deck x 8; Cabin x 3; Flight deck & cabin x 4
PHASE OF FLIGHT	Climb & or descent x 12; After start x 1; Various phases x 2
ENGINE OPERATION	Non steady state engine operation x 15
AIRCRAFT TYPES	BAe 146 x 5; A 330 x 2; A 319 x 2; B757 x 3 B737 x 1; B767 x1; B747 x 1
PREVIOUS REPORTS OF FUMES ON AIRCRAFT	10
FOLLOWING REPORTS OF FUMES ON AIRCRAFT	10
MAINTENANCE FINDINGS	Oil x11; Oil & hydraulic x 2; Unknown x 2 (1 possible oil overfill)
LEVEL OF EFFECT (AT TIME OF EVENT)- Pilots & cabin crew	Incapacitation & or partial incapacitation x 7; Incapacitation & impairment x 2; Impairment x 5

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Airbus patent 2017 & Deutsche Lufthansa patent 2019



(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 3 323 728 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
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(51) Int Cl.:
B64D 13/06 *(2006.01)*

(21) Application number: **16199745.7**

(22) Date of filing: **21.11.2016**

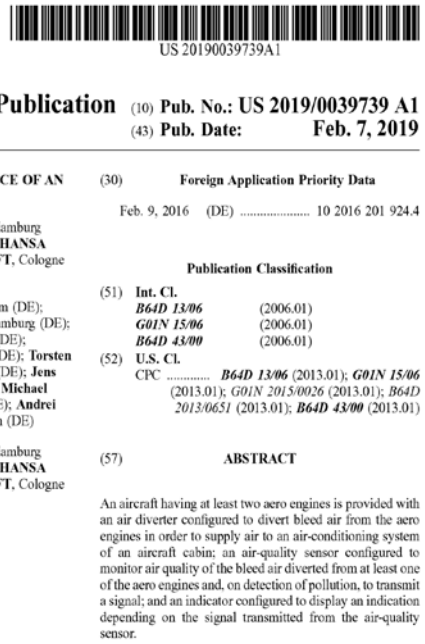
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AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA ME
Designated Validation States:
MA MD

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(54) **SYSTEM AND METHOD FOR DETERMINING THE ORIGIN OF AN OIL LEAKAGE IN AN AIR SUPPLY SYSTEM**



US 20190039739A1

(19) **United States**

(12) **Patent Application Publication**
Winter et al.

(10) **Pub. No.: US 2019/0039739 A1**

(43) **Pub. Date: Feb. 7, 2019**

(54) **AIRCRAFT AND WARNING DEVICE OF AN AIRCRAFT**

(71) Applicants: **Lufthansa Technik AG**, Hamburg (DE); **DEUTSCHE LUFTHANSA AKTIENGESELLSCHAFT**, Cologne (DE)

(72) Inventors: **Kirsten Winter**, Bodenheim (DE); **Tarquinio Witzemann**, Hamburg (DE); **Robert Nyenhuis**, Mainz (DE); **Werner Knorr**, Niddatal (DE); **Torsten Conrad**, Kleinblittersdorf (DE); **Jens Peter**, Saarbruecken (DE); **Michael Mueller**, Saarbruecken (DE); **Andrei Chirokolava**, Saarbruecken (DE)

(73) Assignees: **Lufthansa Technik AG**, Hamburg (DE); **DEUTSCHE LUFTHANSA AKTIENGESELLSCHAFT**, Cologne (DE)

(21) Appl. No.: **16/076,327**

(22) PCT Filed: **Feb. 8, 2017**

(86) PCT No.: **PCT/EP2017/052732**
§ 371 (c)(1),
(2) Date: **Aug. 8, 2018**

(30) **Foreign Application Priority Data**

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Publication Classification

(51) **Int. Cl.**
B64D 13/06 (2006.01)
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B64D 43/00 (2006.01)

(52) **U.S. Cl.**
CPC ***B64D 13/06*** (2013.01); ***G01N 15/06*** (2013.01); *G01N 2015/0026* (2013.01); *B64D 2013/0651* (2013.01); ***B64D 43/00*** (2013.01)

(57) **ABSTRACT**

An aircraft having at least two aero engines is provided with an air diverter configured to divert bleed air from the aero engines in order to supply air to an air-conditioning system of an aircraft cabin; an air-quality sensor configured to monitor air quality of the bleed air diverted from at least one of the aero engines and, on detection of pollution, to transmit a signal; and an indicator configured to display an indication depending on the signal transmitted from the air-quality sensor.

[0007] Due to the complexity of the overall air supply system and the mixing of air coming from different compressed air sources in the system, in case of a contamination in the bleed/compressed air system it is extremely difficult to identify the origin of the contamination.

….it is not possible to identify the engine at fault solely from the perception of the "engine oil smell" in the cabin. ……it is possible that the "engine oil smell" does not occur on the ground, as the operating and ambient conditions of the engines on the ground and in the air are quite different, so that an identification of the engine causing the "engine oil smell" is no longer possible on the ground.

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Factor	AAIB (2029)	Comment
Effect on crew	Most no immediate effects on pilots LT effects?	• Acute effects are common: (Michaelis 2010, 2017) • Acute on chronic pattern (Howard 2017/2018 • LT effects – well documented/ Not OPIDN (Howard 2020) • Turner V East west; Myers (Oregon W/C)…
Irritant effects		Irritant (CAA 2004): + toxic effects (Winder 2002, Michaelis 2017, Howard 2018, EU Regulation CLP 2008), MSDS, EASA/AVOIL 2017, Baker 2012….
Effect	Smell → Stress → Physiological effects (knowledge of source helps)	Toxic mechanism or nocebo (COT 2013)[OPIDN] Lack of education/training Checklists > smoke
Variation among people		• Expected/Diffuse pattern – (Michaelis 2017) • Exposure pattern- Acute/chronic; genetic susceptibility; individual variability; lifestyle; age; environmental factors; others
Smell varies		Very common/ reduces intensity over time

CLP (2008)

- Damage to organs (single/repeat)
- Allergic skin reaction
- Damage fertility/ unborn
- Eye/skin/Respiratory irritation
- Genetic defects
- Allergy or asthma symptoms
- Skin burns/eye damage

Table 2 Aerotoxic syndrome: short- and long-term symptoms

Short term exposure	Long term exposure
Neurotoxic symptoms: blurred or tunnel vision, nystagmus, disorientation, shaking and tremors, loss of balance and vertigo, seizures, loss of consciousness, parathesias;	*Neurotoxic symptoms*: numbness (fingers, lips, limbs), parathesias;
Neuropsychological or Psychotoxic symptoms: memory impairment, headache, light-headedness, dizziness, confusion and feeling intoxicated;	*Neuropsychological or Psychotoxic symptoms*: memory impairment forgetfulness, lack of coordination, severe headaches, dizziness balance, sleep disorders;
Gastro-intestinal symptoms: nausea, vomiting;	*Gastro-intestinal symptoms*: salivation, nausea, vomiting, diarrhoea;
Respiratory symptoms: cough, breathing difficulties (shortness of breath), tightness in chest, respiratory failure requiring oxygen;	*Respiratory symptoms*: breathing difficulties (shortness of breath), tightness in chest, respiratory failure, susceptibility to upper respiratory tract infections;
Cardiovascular symptoms: increased heart rate and palpitations;	*Cardiovascular symptoms*: chest pain, increased heart rate and palpitations;
	Skin symptoms: skin itching and rashes, skin blisters (on uncovered body parts), hair loss;
Irritation of eyes, nose and upper airways.	*Irritation* of eyes, nose and upper airways;
	Sensitivity: signs of immunosuppression, chemical sensitivity leading to acquired or multiple chemical sensitivity
	General: weakness and fatigue (leading to chronic fatigue), exhaustion, hot flashes, joint pain, muscle weakness and pain.

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	No of pilots reporting Symptoms		No of incidents/ symptom		+ oil, hydraulic, deicing fluid				
	Acute	Chronic	Acute	Chronic			Acute	Chronic	
NEUROLOGICAL						X	X	X	
CENTRAL (CNS)						X	X	X	
Incapacity/paralysis; Impaired/loss of consciousness	9 (6%)	1 (1%)	15 (100%)			X	X	X	loss consciousness	semi consciousness
Headache /Pressure in head/ trouble speaking	47 (33%)	21 (15%)	11 (73%)	5 (33%)		X	X	X	headache	headache
Balance problems/erratic movement/ataxia	11 (8%)	7 (5%)	2 (13%)	1 (7%)		X	X	X		
Vision problems/tunnel or double vision/dilated pupils/ nystagmus	11 (8%)	10 (7%)	8 (53%)	1 (7%)		X	X		unresponsive pupils	visual disturbances
PERIPHERAL (PNS) Motor;Sensory;Autonomic						X	X	X		
Shaking/tremors; Inco-ordination/motor response	12 (9%)	17 (12%)	11 (77%)	6 (40%)		X	X	X		shakes/ twitches
Paraesthesiae/numbness in limbs/other; Peripheral neuropathy	12 (9%)	25 (18%)	5 (33%)	7 (46%)	Neurotoxicity, Single & repeat exposure	X	X	X		tingling/ numbness
Sweaty/temperature control/ pallor/flushing/taste	7 (5%)	6 (4%)	3 (21%)	6 (60%)		X	X	X	sweating	sweats/hot/ cold
NEUROBEHAVIOURAL						X	X	X		
NEUROLOGICAL						X	X			
Discomfort/intoxication/disorientation/ confusion	16 (11%)	3 (2%)	10 (66%)	1 (7%)		X	X		confusion/ disorientation	confusion/ disorientation
Behavioural/personality Changes;unreality/anxiety/ depression	1 (1%)	20 (14%)		7 (46%)		X	X	X	unreality	unreality/ anxiety
Dizziness/light-headedness/ lethargy/drowsiness	21 (15%)	9 (6%)	11 (73%)	3 (20%)	Drowsiness/ dizziness:CNS	X	X	X	light headedness	light headedness

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Winder, Michaelis (2005) http://dx.doi.org/10.1007/b107246

Michaelis S, Burdon J, Howard CV. Aerotoxic Syndrome: A New Occupational Disease? Public Health Panorama 2017; 3: 198-211)

Other AIB reports- recommendations & findings

Portugal

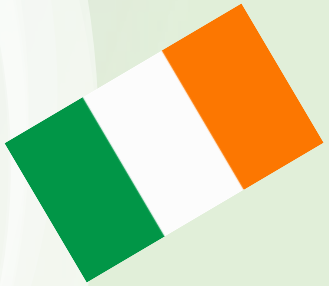
Switzerland





New Zealand





Country	No. Reports/ recommendations		No. Reports/ recommendations
Australia	2/7	Germany	2/5
Sweden	1/4	Spain	1/1
UK	6/17	Austria	1/5
Ireland	1/1	UAE	1/8
Iceland	1/1	Finland	1/4
Total 16 reports/ 10 countries = 53 Recommendations			





France





Canada





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AIB recommendation breakdown

Recommendation	No.	Recommendation	No.
Airworthiness/maintenance/ certification	9	International database	2
Data analysis	3	Research – Oils/Contaminants & effect on health	9
Reporting	3	Treatment protocol	1
Education & training	3	Detection & warning systems	7
Checklist/Oxygen use (100%)	5	Filtration	1
PBE	2	Emergency evacuation procedures	5
Crew/passenger, airport & agency protocols during/post events	7	Safety risk assessment	2

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BEA investigation



Event (2017)

- Airbus A320 / citation / possible exhaust gasses on line up / Partial incapacitation
- O2 masks not used for initial 8 mins
- Pathology – negative result (CO)
- Leak tightness of seals- NFF; Oil leak not found
- Oil chip detector activated 2 days later: NFF
- Contaminants: Acrid/acidic smell: NOx & SO_2, CO
- EASA: Causal link not proven

BUT

- Oil leakage into compressor: Damaged or worn seals; Rough speed changes ×
- TOCP – neurotoxic, >> Samples / symptoms? – Not detected ×
- Hair sample: TCP at environmental levels >> TCP/TOCP exposure excluded ×
- Oil: Can be described as Acrid in addition to dirty socks ✓
- Difficulty in maintenance investigation of oil leakage/fumes ✓
- Exhaust fumes contain >50% oil droplets as particulates (Fushimi (2019) ✓
- Could be a combination of exhaust fumes & oil leakage ✓

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https://www.bea.aero/en/investigation-reports/notified-events/detail/serious-incident-to-the-airbus-a320-registered-ec-hqj-and-operated-by-vueling-on-17-11-2017-en-route/

Conclusion

Although common features

- Events consistent exposure to oil fumes
- Lack of of knowledge on how/why oil fume events occur
- Incomplete information
- Reluctance to mention oil as factor
- Lack of appreciation of oil & supply air system
- Reliance on failure conditions/not normal operation
- Maintenance procedures inadequate for oil fume events
- Sensors & supply air filtration required
- Under appreciation of health effects
- Need for suitable medical protocol

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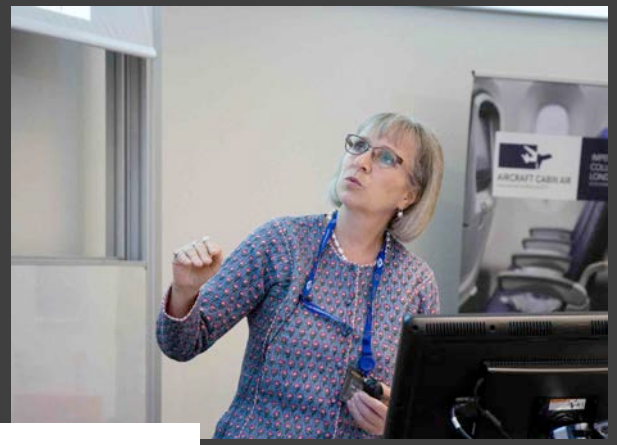
Thank you

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44 (0) 7880554551





Cabin Air Quality: Safety Analysis and Certification





- Dr Susan Michaelis: PhD, MSc, ATPL
  Honorary Senior Research Fellow,
  University of Stirling
- Air Accident investigator (MSc, Cranfield (2016))

2021 Aircraft Cabin Air Conference:
15 - 18 March 2021

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Oil usage environment

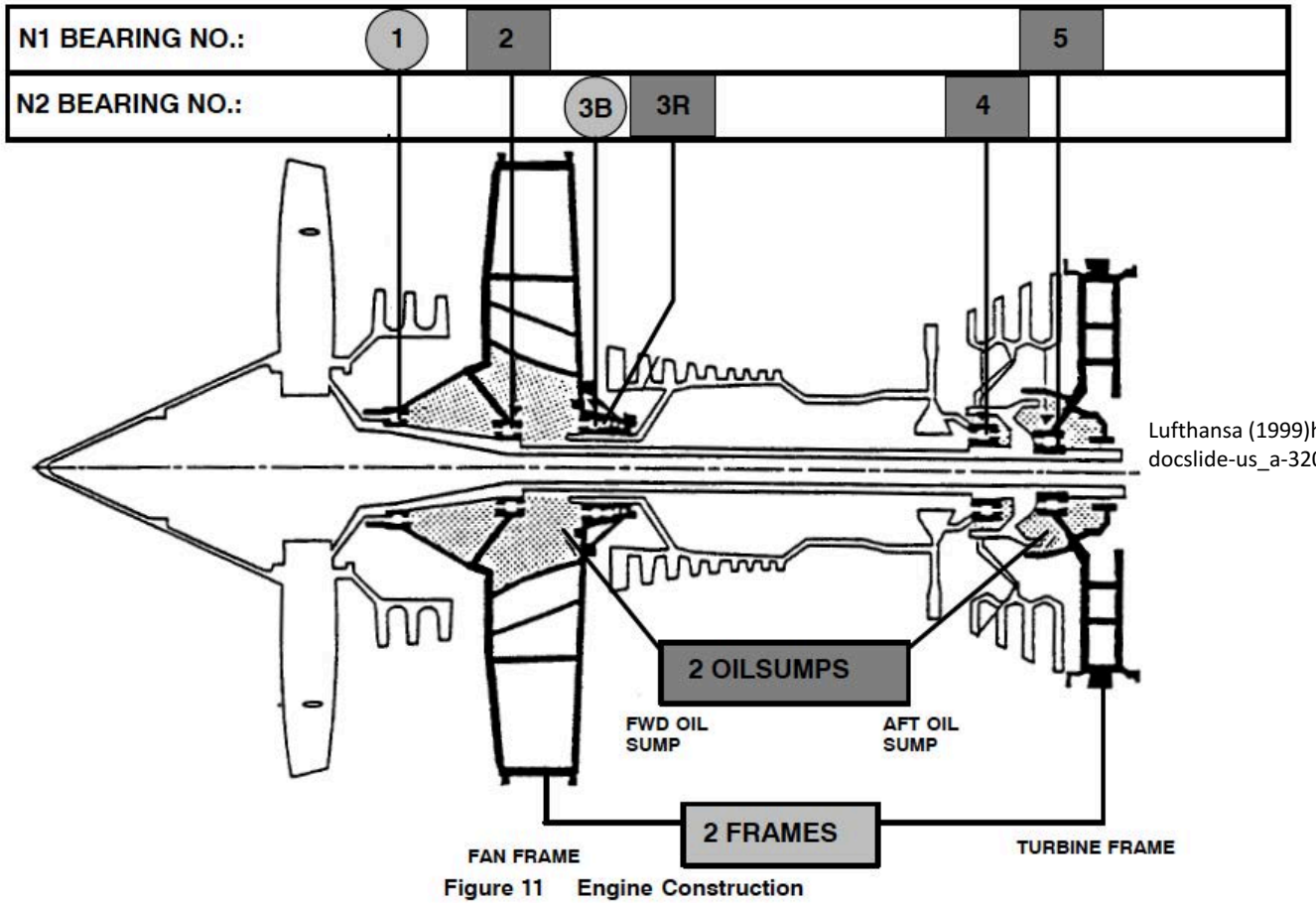
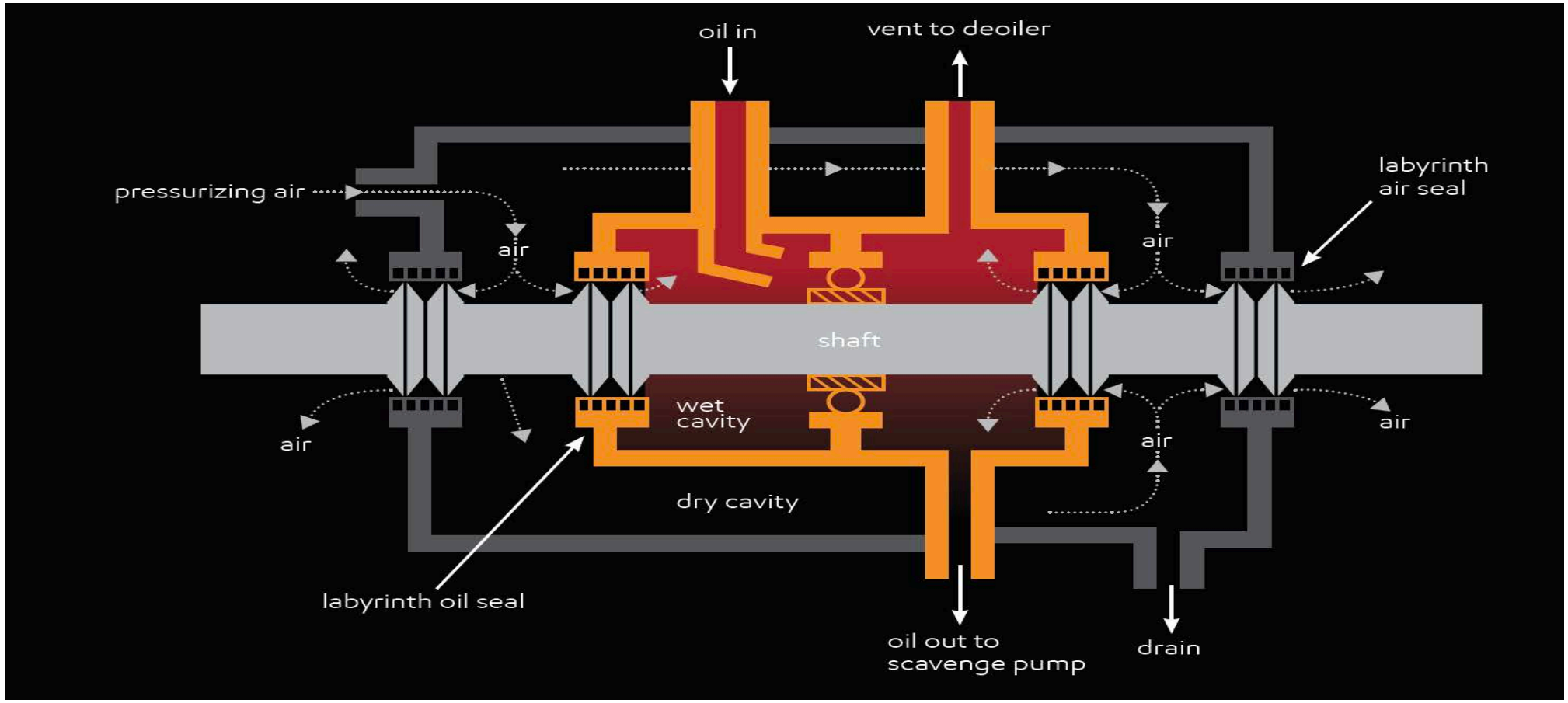


Figure 11 Engine Construction

Lufthansa (1999)https://www.metabunk.org/attachments/docslide-us_a-320-engine-pdf.16733

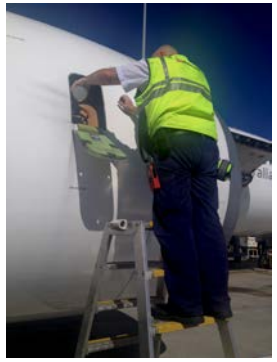
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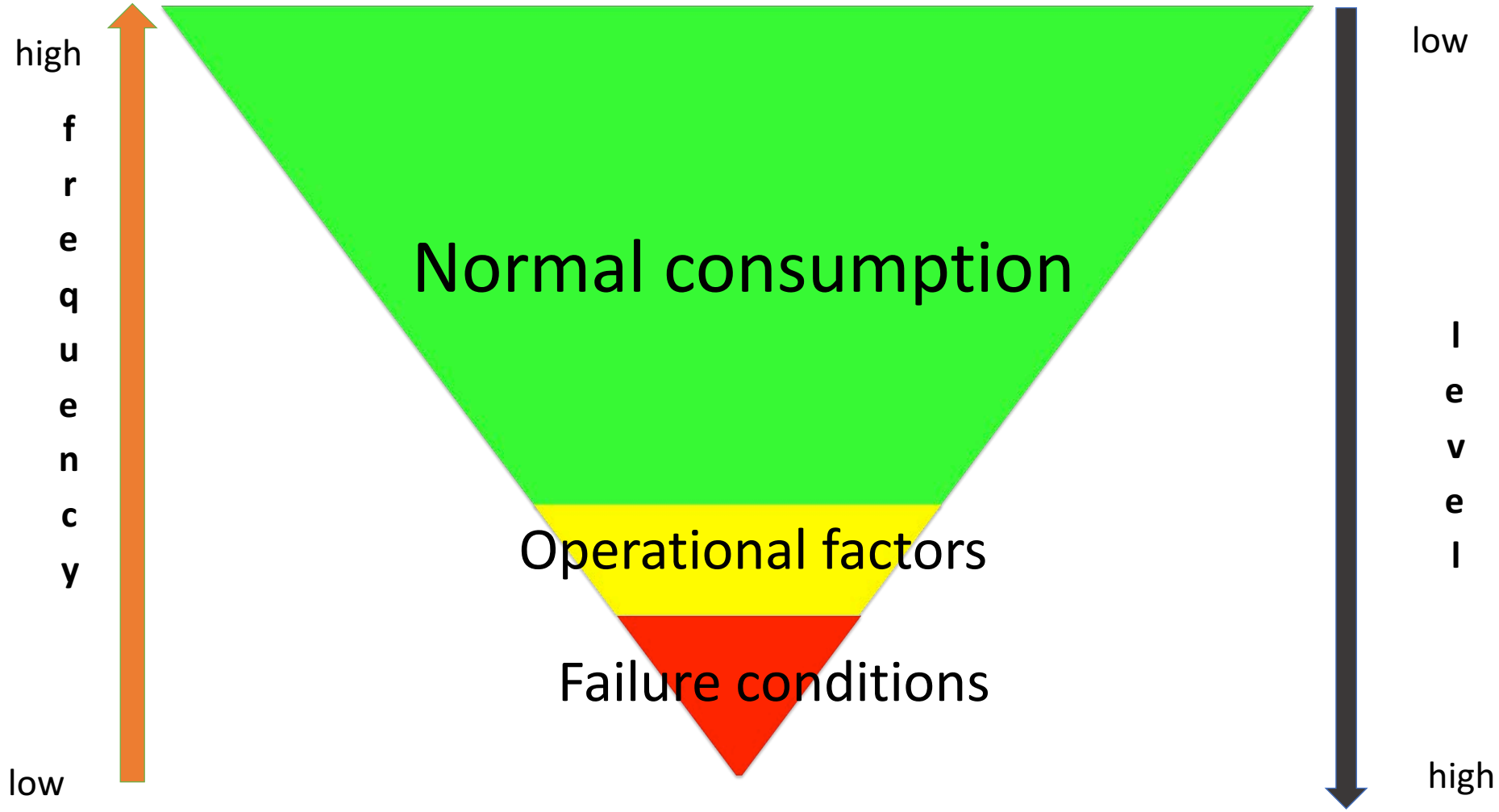
Oil bearing chamber



https://www.exxonmobil.com/en/aviation/knowledge-library/resources/jet-engine-oil-system-2

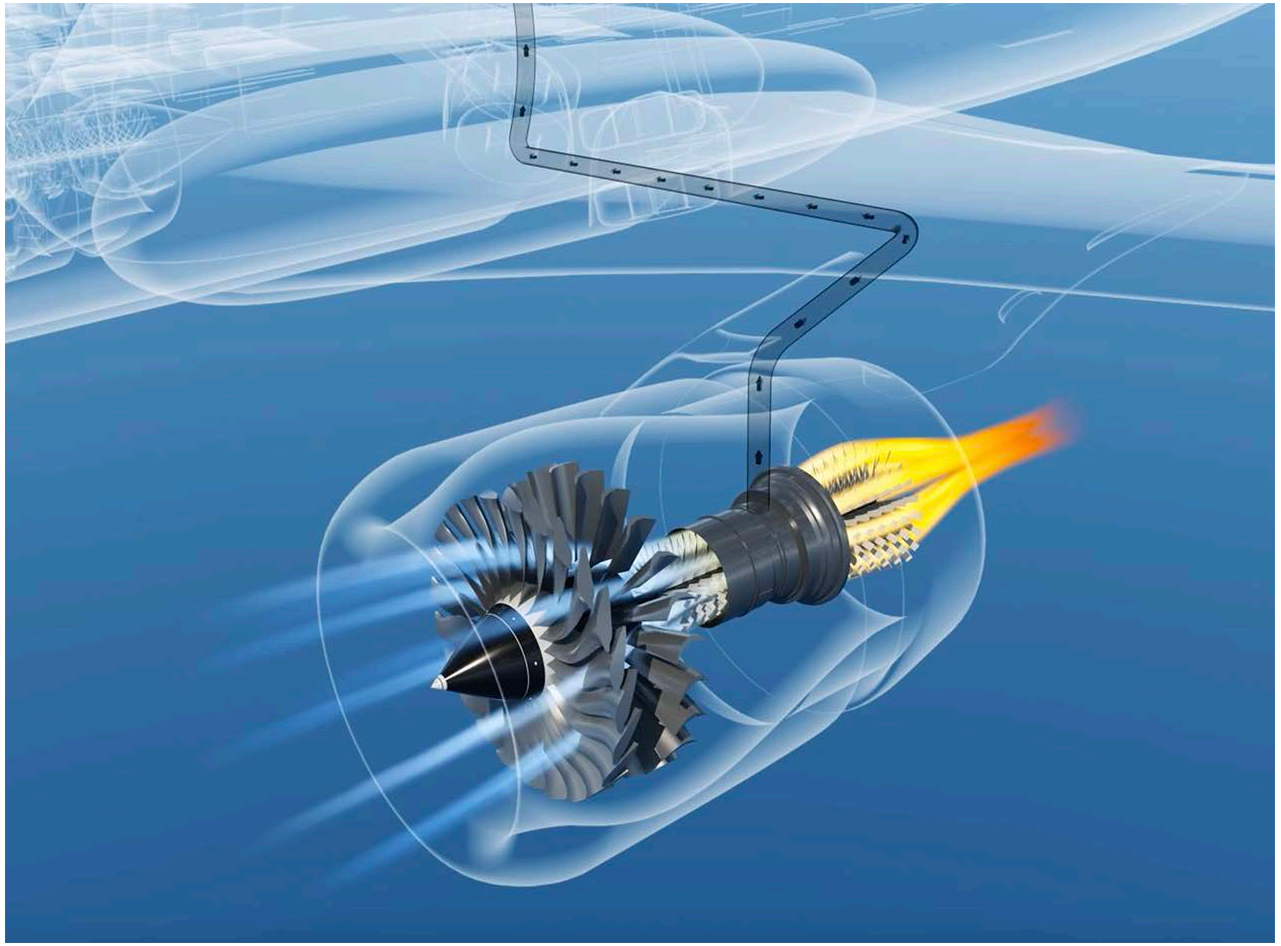
Oil consumption





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Engine to cabin

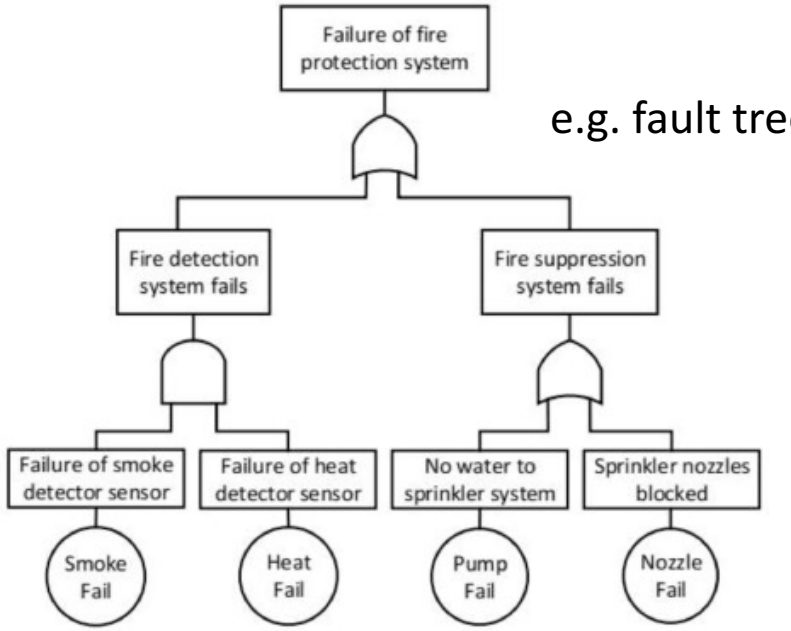


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Certification/demonstration of compliance

Engine/Airframe

- CS-E 510 / CS-APU 210 & AMC – Safety analysis
- CS-25. 1309 – Equipment systems & installations/ AMC -System design & analysis



e.g. fault tree analysis

Ventilation system

- CS-25.831 & AMC – Ventilation
  - CO, CO_2, O_3, temp, airflow
  - NRC, 2001, ASHRAE 161P, ASD-STAN standards such as DO-160, SAE ARP 85, ASHRAE IAQ standard, SAE AS 5379, ASHRAE research project 957-RP, NIOSH report/Alaska Airlines, CDC…… (FAA) *
  - Source of data to show compliance that incapacitation will not occur greater than allowed is up to the manufacturer.*

*Michaelis, S. (2016) "Implementation Of The Requirements For The Provision Of Clean Air In Crew And Passenger Compartments Using The Aircraft Bleed Air System", Cranfield University, UK. Cranfield MSc Thesis https://bit.ly/3ostNBU; https://doi.org/10.4236/eng.2018.104011

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Failure probability

CS-E 510 & CS-APU 210 & AMC - Safety analysis

Probability of failure conditions

- Includes compressor bleed systems
- Hazardous engine/APU effects/ Extremely remote = $<10^{-7}$/ engine/APU flight/operating hour

  = 1 in 10 million
  - Toxic products → incapacitate crew or pax
  - e.g.: degradation of oil leaking into compressor airflow

- Major engine/APU effects / Remote

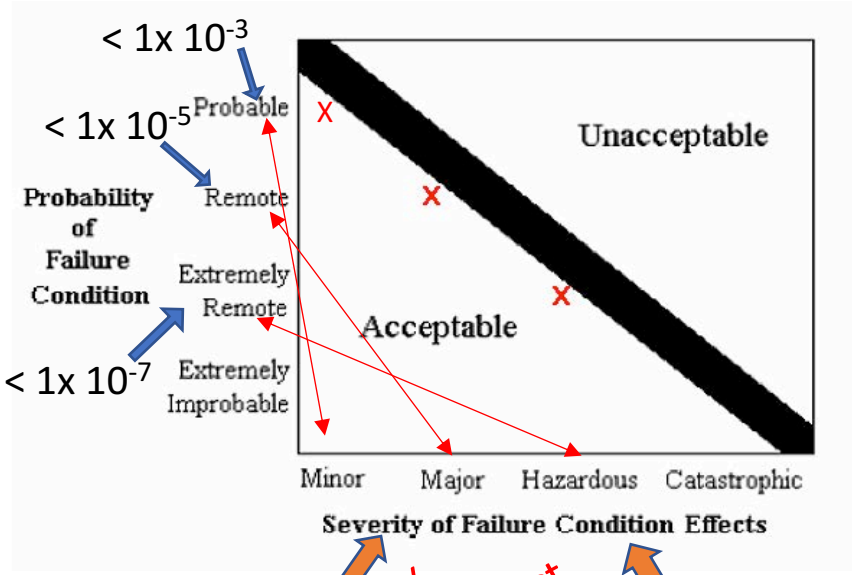
  = $< 10^{-5}$/ engine/APU flight hour = 1 in 100,000
  - Toxic products in bleed air →degrade crew performance

Effects of failure may rely on engineering judgement and may not be proved absolutely

CS 25.1309 & AMC

Probability of failure conditions & effects

Inverse relationship



Remote = Unlikely to occur to each aircraft during its total life

Impairment/ Major failure effect

Incapacitation/ Hazardous failure effect

Quantitative & Qualitative analysis
(Including engineering & operational judgement)

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Normal operations V Certification (failure effects)

- Oil system - permissible oil consumption – e.g.: 0.1-1 quart/hour
  - Most will go out vent/breather system
  - Some can go back into compressor > cabin air supply
  - Oil seals most efficient at steady state operation
  - Seals minimize leakage/flow (not prevent)
  - Sealing bearing sumps difficult as near ambient pressure
  - Other design factors to minimize leakage + positive pressure
- Permissible very low level (background) oil leakage
- Increases with seals not at operational temps & pressures/changes in power (transients)/ bleed air configuration changes / low power settings
- Oil exposed to high temperature / water > decomposition / carboxylic acids (dirty socks), complex mixture

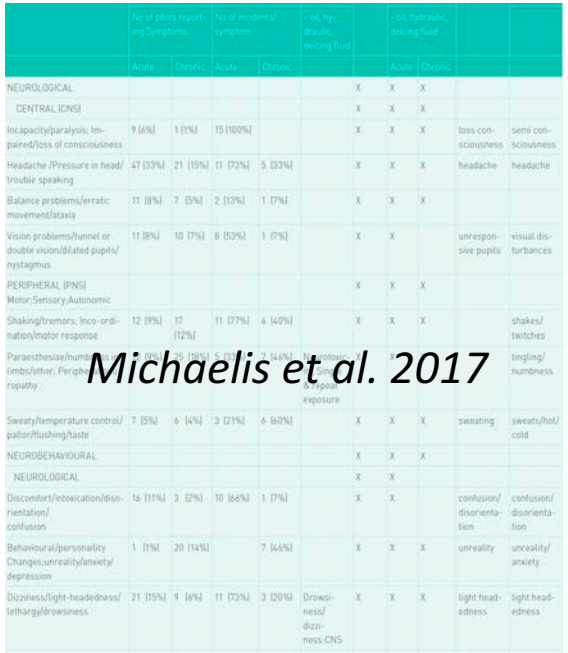
Awareness of leakage in normal operations - limited examples

- A zero-leakage seal is an oxymoron (Chupp et al., 2006 – GE global research, Glenn research centre)
- Labyrinth seals - Pressurized to minimize oil leakage along shaft (FAA, 2012)
- The scavenged oil flow is slightly lower than the supply flow due to the normal oil consumption through the deoiler, oil seals and oil leaks (ExxonMobil 2012)
- Changes in bleed system pressure can disrupt seal performance, causing oil to leak (ExxonMobil 2018)
- Just about all known seals will leak, with seals designed to limit leakage and no such thing as a seal that does not leak (Flitney, 2014)
- Oil pyrolysis measurements identified that “oil contamination in the compressor will result in a fog of very fine droplets in the bleed air under most operating conditions (Jones, 2017)
- Most engines might have a permanent (non-event) turbine oil leak rate – into cabin (EASA, 2017)

‘every engine leaks oil from its seals and bearings’ – BAe 1999

Acute effects - Exposure to turbine oils

- MSDSs > Elevated temps >> headaches, nausea, eye, nose & throat irritation (ExxonMobil, 2018)
- Product labelling
- Hazard classifications: (EU Reg CLP) / GHS
- Hazard databases: HSDB, ICSC, NIOSH *
- Extensive scientific published literature
- Michaelis et al (2017)- Diffuse pattern of effects
- Acute illness > severely incapacitating COT (2013)
- OHRCA (2009)
- Regulator/AIB reports reports
- ICAO (2015)
- + Complex heated mixture



Michaelis et al. 2017

CLP (2008)

- Damage to organs (single/repeat)
- Allergic skin reaction
- Damage fertility/unborn
- Eye/skin/Respiratory irritation
- Genetic defects
- Allergy or asthma symptoms
- Skin burns/eye damage



- Consistent with Michaelis et al (2017) *e.g., CNS PNS, neurobehavioral GI, respiratory-cardiovascular, rheumatological, fatigue, irritation of skin, eyes, mucous membranes, respiratory tract, effects on blood….*

Frequency of exposure

- Explained by design: Exposure occurs in all flights – Very low levels
  - + Fume events - transient/normal operations or far less frequent failure (Michaelis 2016, 2018)

Other fume/smoke reports:

- Oil fume reports by pilots - 1% of flights – COT (2007)
- Acute effects - 30% - CAA MORs (Michaelis,2010)
- 2.1 per 10,000 flights / underreported (Shehadi, 2015)
- Nuisance fume events- underreported EASA (2011)
- 26% of reports – Oil / hydraulic fluids (Anderson,2021)



UNDER-REPORTING (FAA,2006; EASA, 2011) is WIDELY RECOGNISED

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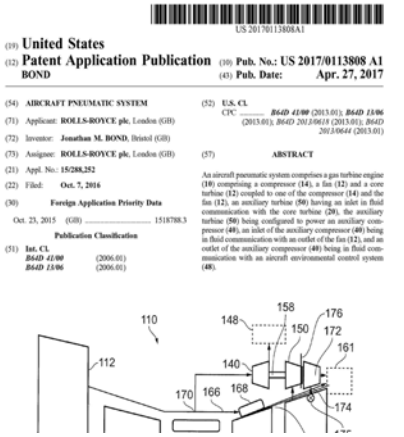
Patents

- Where air is bled from the compressor, there is a risk that toxins from the engine oil system may be present in the bled air, thereby resulting in unacceptable air quality. (Rolls Royce GB, 2017)

- Any oil / oil vapor that escapes the seals of the bearing is allowed into the inner volume of the engine rotating parts which can get into the compressor airstream. It is when this oil product gets into the compressor air stream that the potential for contamination of the bleed air supplied to the aircraft can occur. (Boeing, 2017)

- Typically, seals are used to limit oil escape, but as seals are not completely leakproof it is normal to ensure that the pressure outside the bearing chamber is higher than the pressure within the bearing chamber. In this way air leaks into the chamber through the seals, preventing oil escape. (Rolls Royce GB, 2016)

- Sealing systems are not always totally effective, and as a result there may be leakage of fuel or lubricant into the bleed air. (Allied Signal, 1998)


US 20170113808A1

(19) United States

(12) Patent Application Publication

BOND

(10) Pub. No.: US 2017/0113808 A1

(43) Pub. Date: Apr. 27, 2017

(54) AIRCRAFT PNEUMATIC SYSTEM

(71) Applicant: ROLLS-ROYCE plc, London (GB)

(72) Inventor: Jonathan M. BOND, Bristol (GB)

(73) Assignee: ROLLS-ROYCE plc, London (GB)

(21) Appl. No.: 15/288,252

(22) Filed: Oct. 7, 2016

(30) Foreign Application Priority Data

Oct. 23, 2015 (GB) 1518788.3

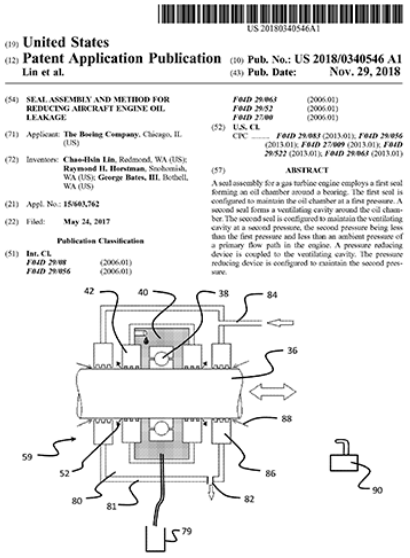
Publication Classification

(51) Int. Cl.
B64D 41/00 (2006.01)
B64D 13/06 (2006.01)

(52) U.S. Cl.
CPC B64D 41/00 (2013.01); B64D 13/06 (2013.01); B64D 2013/0618 (2013.01); B64D 2013/0644 (2013.01)

(57) ABSTRACT

An aircraft pneumatic system comprises a gas turbine engine (10) comprising a compressor (14), a fan (12) and a core turbine (12) coupled to one of the compressor (14) and the fan (12), an auxiliary turbine (50) having an inlet in fluid communication with the core turbine (20), the auxiliary turbine (50) being configured to power an auxiliary compressor (40), an inlet of the auxiliary compressor (40) being in fluid communication with an outlet of the fan (12), and an outlet of the auxiliary compressor (40) being in fluid communication with an aircraft environmental control system (48).


US 20180340546A1

(19) United States

(12) Patent Application Publication

Lin et al.

(10) Pub. No.: US 2018/0340546 A1

(43) Pub. Date: Nov. 29, 2018

(54) SEAL ASSEMBLY AND METHOD FOR REDUCING AIRCRAFT ENGINE OIL LEAKAGE

(71) Applicant: The Boeing Company, Chicago, IL (US)

(72) Inventors: Chao-Hsin Lin, Redmond, WA (US); Raymond H. Hovelman, Snohomish, WA (US); George Bates, III, Bothell, WA (US)

(21) Appl. No.: 15/603,762

(22) Filed: May 24, 2017

Publication Classification

(51) Int. Cl.
F04D 29/08 (2006.01)
F04D 29/056 (2006.01)
F04D 29/52 (2006.01)
F04D 27/00 (2006.01)

(52) U.S. Cl.
CPC F04D 29/083 (2013.01); F04D 29/056 (2013.01); F04D 27/009 (2013.01); F04D 29/522 (2013.01); F04D 29/063 (2013.01)

(57) ABSTRACT

A seal assembly for a gas turbine engine employs a first seal forming an oil chamber around a bearing. The first seal is configured to maintain the oil chamber at a first pressure. A second seal forms a ventilating cavity around the oil chamber. The second seal is configured to maintain the ventilating cavity at a second pressure, the second pressure being less than the first pressure and less than an ambient pressure of a primary flow path in the engine. A pressure reducing device is coupled to the ventilating cavity. The pressure reducing device is configured to maintain the second pressure.

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System V certification based on failure probability



Failure probability- Airworthiness certification

- Failure analysis + reporting system verification
- Incapacitation < 1 in 10,000,000 engine/airframe flight hours (10^{-7}) – extremely remote
- Impairment < 1 in 100,000 engine/airframe flight hours (10^{-5}) – remote

+ Reporting system not working

Design problem - Normal operation

- This is the way the system works
- Low level oil leakage is normal / not restricted to failure conditions
- Design problem

11. *Check the category that best describes the cause of the unsafe condition addressed by this AD:*

__x__ Design Problem	____ Unapproved Parts	____ Operational
____ Maintenance	____ Quality Control Problem**	____ Other (specify):
	**Reporting Reqt Needed? ____	

Project Engineer: [redacted] ANM-116 Date: Tuesday, March 25, 2003

AEG Representative: _____ Date: _____

FAA, 2003

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Other considerations of failure probability

- Basic regulation 2018/1139 & CS 25.1309 a & AMC
- System & equipment
  - Designed to function as intended under any foreseeable operating conditions
  - Function as intended under any foreseeable operating conditions
  - System/ equipment not a source of danger in themselves
  - Foreseeable failures
  - Not for design features that have been shown to negatively impact safety

Products must be designed to minimise the emissions arising from the evaporation or discharge of fluids during the total range of normal operations.

A Generic Risk Assessment

Potential Consequence of an Hazardous Fume			Increasing Probability →				
Rating	People	Increasing Severity ↓	A Extremely Improbable < 1x10-9	B Extremely Remote < 1x10-7	C Remote < 1x10-5	D Probable < 1x10-3	E Frequent > 1x10-3
0	**No adverse effect**	Pilots - no effect Others - inconvenience					
1	**Minor adverse effect** (Slight Impairment)	Pilot – no physical discomfort and slight increase in workload. Others – physical discomfort					
2	**Major adverse effect** (Impairment)	Pilots – Physical discomfort and increase on workload, impaired crew efficiency. Others – physical distress					
3	**Hazardous adverse effect** (Significant impairment)	Pilots – physical distress, impaired ability to perform tasks accurately or completely. Others – serious physical distress.					
4	**Hazardous adverse effect** (Single fatality or serious injury)	Pilots – Serious or fatal injury to one pilot or other crew members					
5	**Catastrophic Effect**	**Multiple fatalities (Normally through hull loss)**					

Edwards C. (2019)Making the Safety Case for Aircraft Operators (Fume Risk in the Cabin/Cockpit), Journal of Health and Pollution, Vol. 9, No. 24 (Dec. 2019). https://doi.org/10.5281/zenodo.4464533

Conclusions 1.

- Use of bleed air system can not meet design certification requirements
- Failure probability analysis is not suitable for use of bleed air system for ventilation
- Failure analysis may capture failure conditions but not normal low-level leakage of oil into compressor
- Impairment due to oil fumes is > certification allows
- Reporting system is not capturing most fume events in normal operation
- Use of bleed air for ventilation is a design flaw.

Conclusions 2.

- Effective filtration of the bleed air is urgently required
- Future aircraft to no longer use bleed air for breathing air
- Contaminated air detection systems
- Regulators MUST start to listen
- Educate crew/operators on the need to report all fume events
- AIBs to investigate fume events as safety threat



Thank you

Susan Michaelis
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Honorary senior Research Fellow,
University of Stirling

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susan@susanmichaelis.com

44 (0) 7880554551

- Michaelis, S. (2016) "Implementation Of The Requirements For The Provision Of Clean Air In Crew And Passenger Compartments Using The Aircraft Bleed Air System", Cranfield University, UK. https://bit.ly/3ostNBU
- Michaelis, S. (2018) Aircraft Clean Air Requirements Using Bleed Air Systems. Engineering, 10, 142-172. https://doi.org/10.4236/eng.2018.104011

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IATA Perspective on Cabin Air Quality Standards Development

Dragos Munteanu, IATA



International

Aircraft Cabin Air Conference 2021

Online, 15-18 March 2021

Identifying the Issues

- Safety Management Systems Approach
- IATA Cabin Operations Safety Best Practices Guide
- Dealing with Fumes Events
- Report
- Investigate

Standards Development

- Safety will always be the Number 1 priority of the Aviation Industry
- Air Transport is in its biggest ever crisis – International Passenger demand is less (-) 85.6% compared to 2019
- IATA analysis shows that already 4.6 Million Aviation Jobs are lost due to the pandemic (almost half of the pre-pandemic figures)
- 46 Million jobs lost in the aviation supported roles
- Safe Recovery of the Industry – by 2024?

Cabin Air - Existing studies

EASA (European Aviation Safety Agency) Final Report EASA_REP_RESEA_2014_4 Research Project: CAQ Preliminary cabin air quality measurement campaign (published 21/03/2017): “due to the exceptional high air exchange rates in aircraft, the cabin air has been proven to be less polluted compared to normal indoor environments (e.g., offices, dwellings, etc.).”

“Research and scientific reviews conducted over the past decades have concluded that a causal link between exposure to cabin/cockpit air contaminants and reported health symptoms is unlikely.”

Standards Development

- Concerns of the civil aviation stakeholders regarding the process of drafting EN 17436 Cabin air quality on civil aircraft – Chemical compounds.
- Proper inclusion of all stakeholders
- The justifications for the standard are highly contentious and not supported by evidence. Aviation medical experts refute many statements in the standard.
- EASA workshop January 2020 – More research needed
- More studies are in progress

Cabin Air – Planned studies

In the USA, FAA (Federal Aviation Administration) has started a project to evaluate possible sensors for bleed air monitoring. This research should be completed, and sufficient data gathered on the potential feasibility of sensors before a CEN Standard is published.

More studies

EASA

(a) RES.003 Research study on cabin and cockpit air quality which should deliver a report in 2021 and

(b) RES.030 Cabin Air Quality – Chronic exposure to contamination events which would start in 2021.

- As more research is needed the CEN standard drafting should be put on hold.
- The current proposal is prescriptive in an age of performance-based standards in aviation

Conclusion

EASA has performed several studies on cabin air quality which revealed that the air quality onboard of aircraft is better than most indoor environments.

There is no consensus in the aviation community

Standards should not be rushed

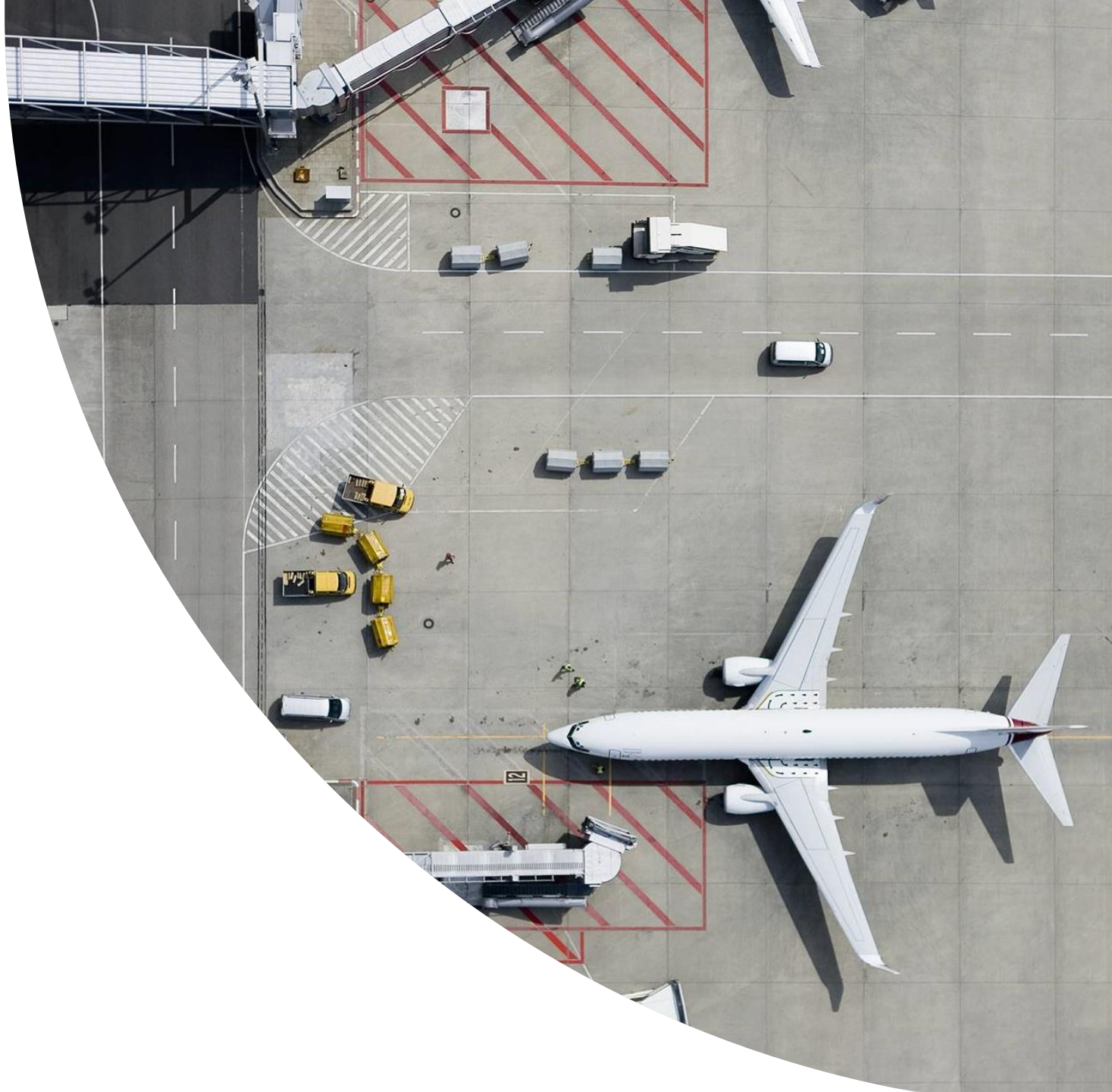
More research is needed

All stakeholders need to be properly involved in the standardization activities following the established procedures and processes in civil aviation safety

Thank you!

IATA EUR Safety & Flight Operations

munteanud@iata.org



International Aircraft Cabin Air Conference 2021

Online, 15 – 18 March 2021



Operational Aspects of Contaminated Air – An Engineer's Perspective

Ricardo Pavia

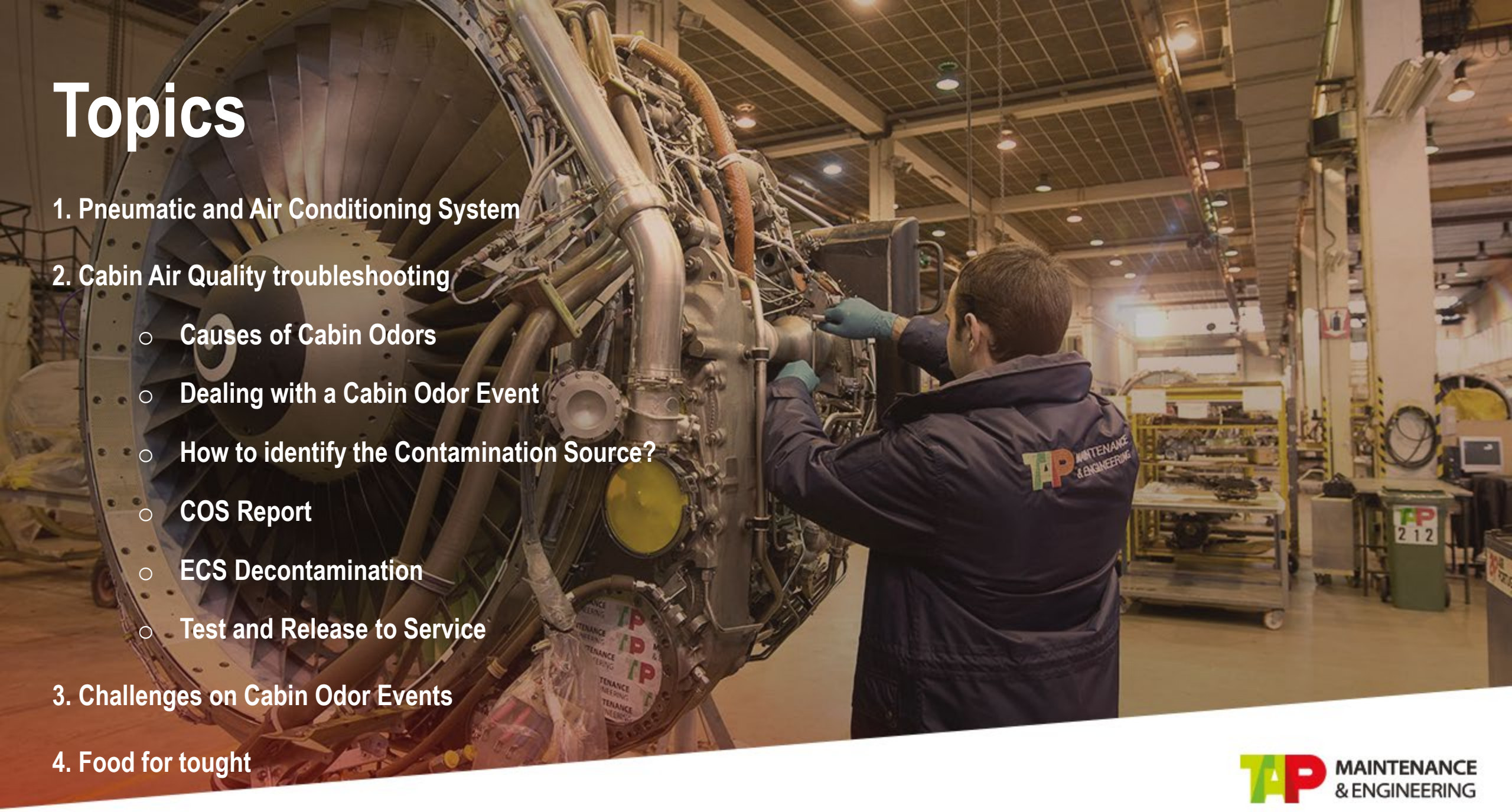
TAP M&E Systems Engineering

A STAR ALLIANCE MEMBER

TAP MAINTENANCE & ENGINEERING

Topics

1. Pneumatic and Air Conditioning System
2. Cabin Air Quality troubleshooting
    - Causes of Cabin Odors
    - Dealing with a Cabin Odor Event
    - How to identify the Contamination Source?
    - COS Report
    - ECS Decontamination
    - Test and Release to Service
3. Challenges on Cabin Odor Events
4. Food for tought

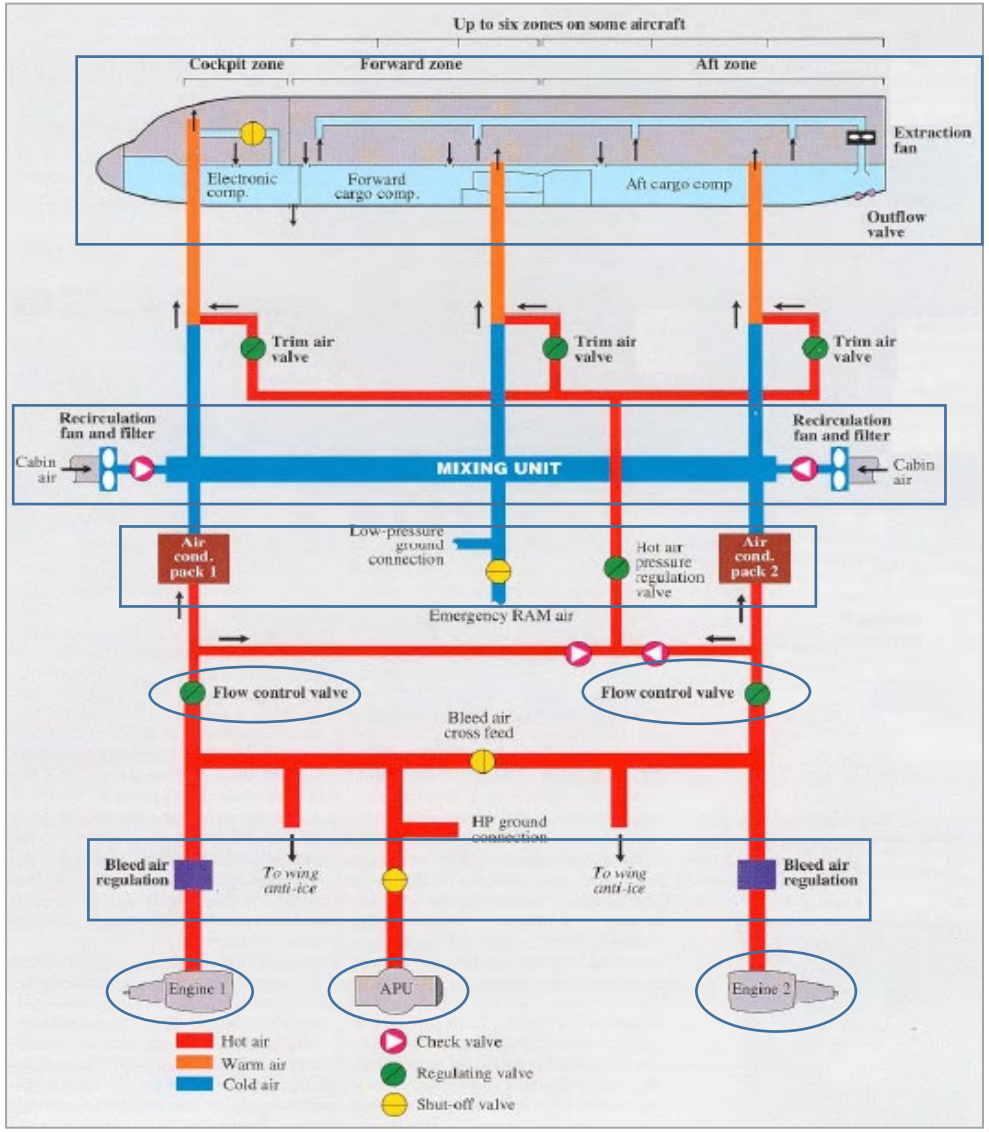


TAP MAINTENANCE & ENGINEERING

1. Pneumatic and Air Conditioning System

Layout

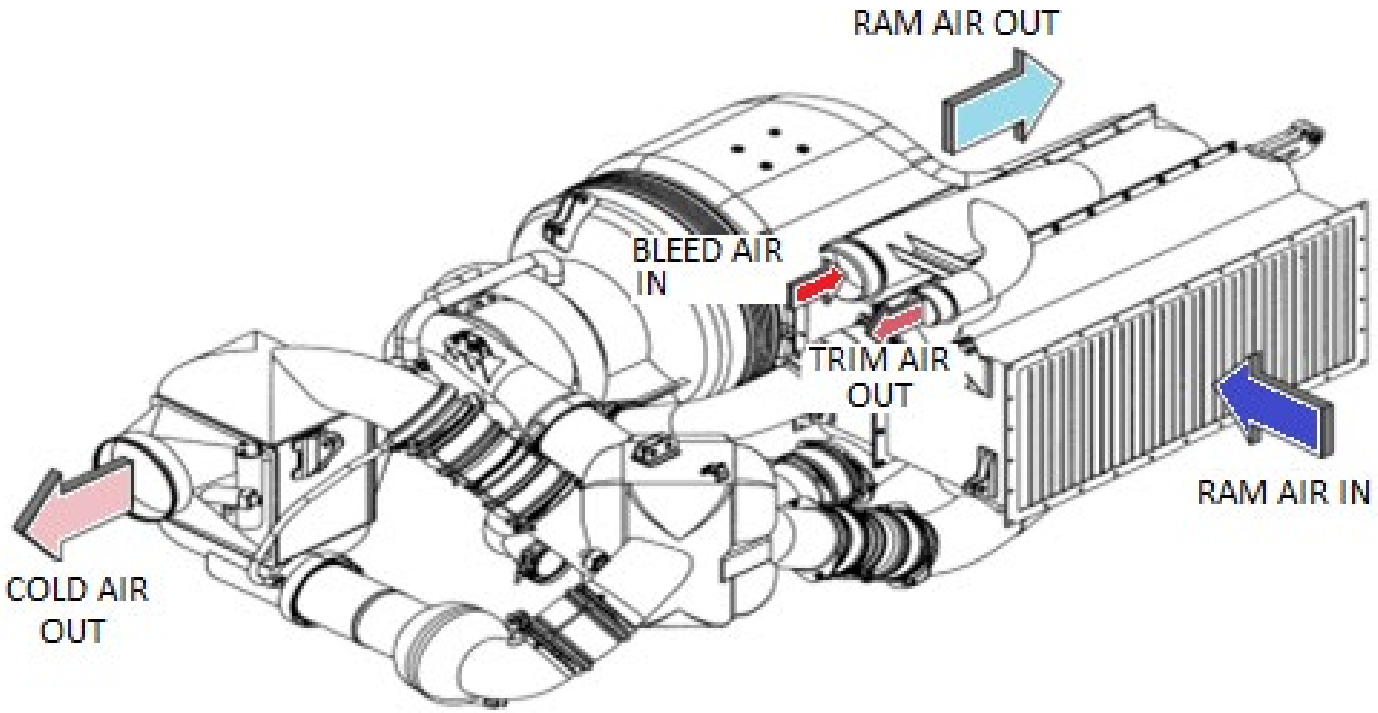
- ✓ The air is provided to cabin with a possibility of adding hot air if required
- ✓ Mixer Unit receive fresh air from the packs and the recirculation air from cabin
- ✓ Air Conditioning Packs are responsible to dehumidify and reduce the air temperature
- ✓ Part of the regulated air is provided to the Air Conditioning Packs
- ✓ The air is regulated in pressure and temperature by the pneumatic system
- ✓ Air is bled from Engines or APU in flight



Source: Airbus Fast 19

1. Pneumatic and Air Conditioning System

Air Conditioning Pack



- Apply a visual inspection for **oil traces** and **oil smell** on pack components

- **High complexity** to understand the affected contaminated components

AOG – Aircraft On Ground

If contaminated, a complete pack replacement could take **1 day** per each Air Conditioning Pack

2. Cabin Air Quality Troubleshooting

Causes of Cabin Odors

EXTERNAL Causes



Pollens



Exhaust fumes from other aircrafts



Pollution



Birds



Cleaning agent residues



De-icing fluid



Hydraulic fluid leaks

2. Cabin Air Quality Troubleshooting

Causes of Cabin Odors

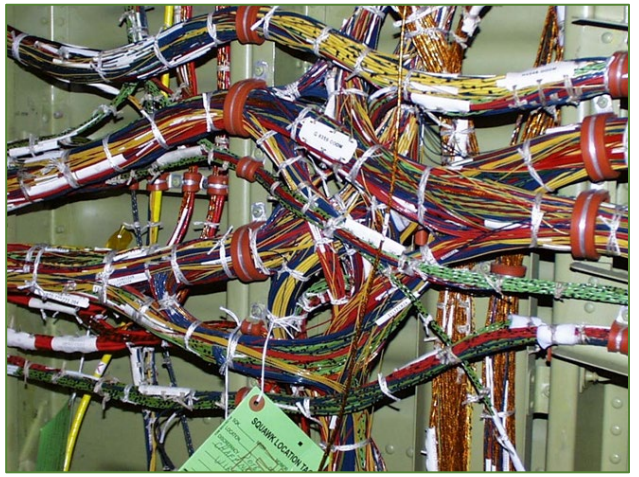
INTERNAL Causes



Galley equipment (i.e. ovens, coffee makers, etc)



Toilet fluid spillage, leakage and also unapproved mixing of different disinfectant fluids in the toilet.



Damaged electrical wiring or components



APU or Engine oil leaks into the bleed system that leads to ECS contamination



Spillages within cargo compartments

2. Cabin Air Quality Troubleshooting

Dealing with a Cabin Odor Event

First Step – How to identify the Contamination Source?

- Analyze the Cabin Odor Sheet
- Identify the contamination source

Second Step – ECS Decontamination

- ECS Decontamination if applicable
- Replace the Engine or APU if applicable

Third Step – Test and Release to Service

- Test the ECS on ground for any odor at cabin
- Put the Aircraft back in service for flight



2. Cabin Air Quality Troubleshooting

How to identify the Contamination Source?

- COS report
- Visual and inspection for odor on APU and Engines for oil leakage
- ERU (Engine Run Up) to identify the correct source of odors
- Flight Crew co-operation on troubleshooting (if possible)
- MMEL for troubleshooting proposes (i.e. bleed OFF or ECS OFF)
- Aerotracer (equipment to measure the type of contamination)
- MMEL dispatch for later corrective actions when people, components and slot are not available.



Difficulty to identify the exact source of contamination

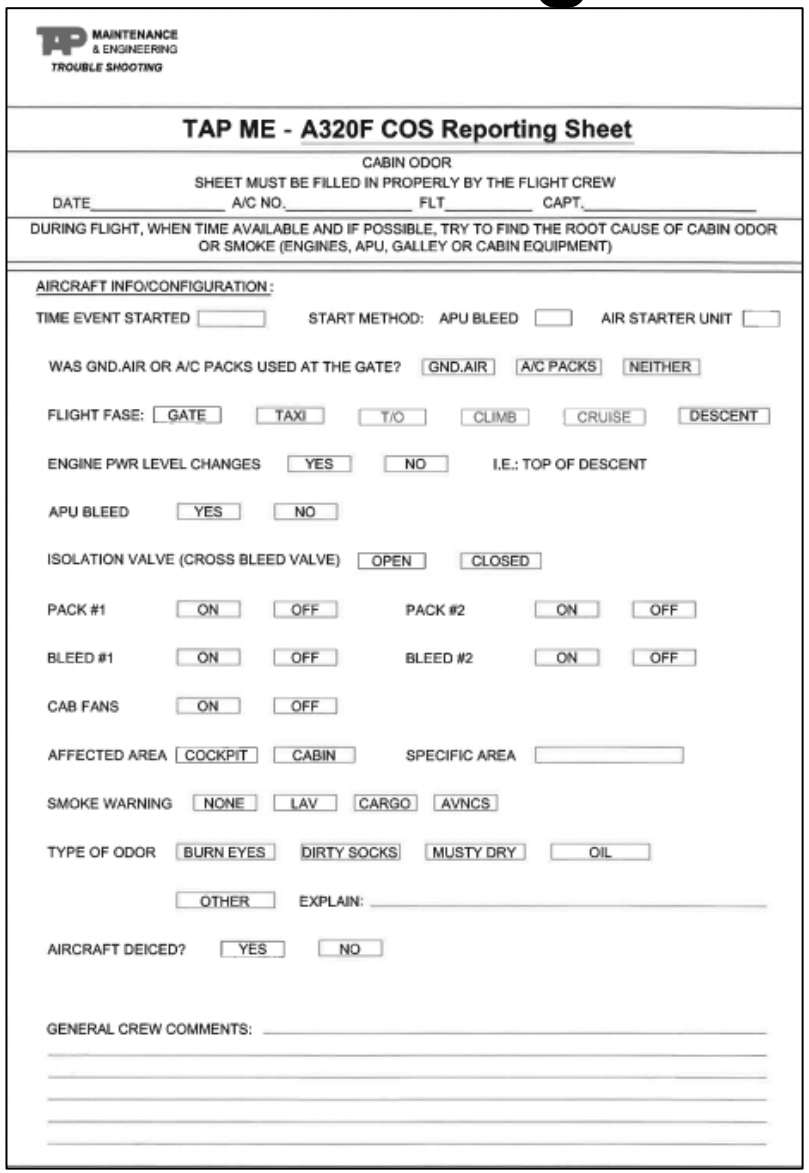
2. Cabin Air Quality Troubleshooting

COS Report

Importance of **COS** report filled by **Flight Crew**

Includes:

- Aircraft Configuration | Pre flight / Time of Event
- Pneumatic/Bleed Configuration
- Air Conditioning Configuration
- Description/Type of the Odor



MAINTENANCE & ENGINEERING
TROUBLE SHOOTING

TAP ME - A320F COS Reporting Sheet

CABIN ODOR
SHEET MUST BE FILLED IN PROPERLY BY THE FLIGHT CREW
DATE_____ A/C NO._____ FLT_____ CAPT._____

DURING FLIGHT, WHEN TIME AVAILABLE AND IF POSSIBLE, TRY TO FIND THE ROOT CAUSE OF CABIN ODOR OR SMOKE (ENGINES, APU, GALLEY OR CABIN EQUIPMENT)

AIRCRAFT INFO/CONFIGURATION:

TIME EVENT STARTED ☐ START METHOD: APU BLEED ☐ AIR STARTER UNIT ☐

WAS GND.AIR OR A/C PACKS USED AT THE GATE? GND.AIR A/C PACKS NEITHER

FLIGHT FASE: GATE TAXI T/O CLIMB CRUISE DESCENT

ENGINE PWR LEVEL CHANGES YES NO I.E.: TOP OF DESCENT

APU BLEED YES NO

ISOLATION VALVE (CROSS BLEED VALVE) OPEN CLOSED

PACK #1 ON OFF PACK #2 ON OFF

BLEED #1 ON OFF BLEED #2 ON OFF

CAB FANS ON OFF

AFFECTED AREA COCKPIT CABIN SPECIFIC AREA

SMOKE WARNING NONE LAV CARGO AVNCS

TYPE OF ODOR BURN EYES DIRTY SOCKS MUSTY DRY OIL

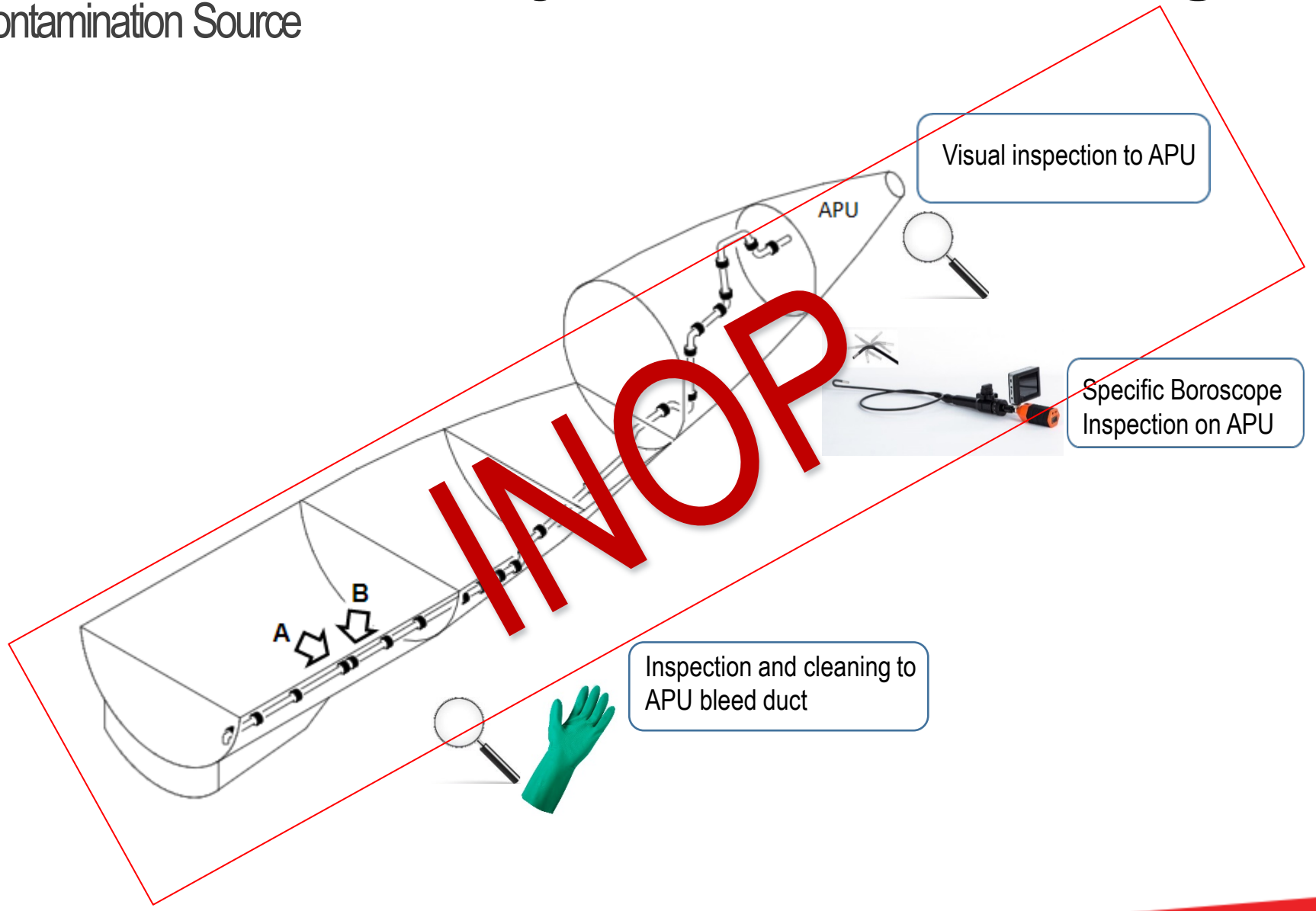
OTHER EXPLAIN: _____

AIRCRAFT DEICED? YES NO

GENERAL CREW COMMENTS: _____

2. Cabin Air Quality Troubleshooting

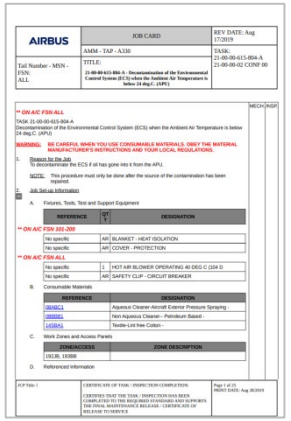
APU as Contamination Source



2. Cabin Air Quality Troubleshooting

ECS Decontamination

Initiate the AMM Decontamination procedures


AIRBUS

JOB CARD

REV DATE: Aug 17/2019

AMM - TAP - A330

TASK: 21-00-00-615-804-A
21-00-00-02 CONF 00

Tail Number - MSN - FSN: ALL

TITLE:
21-00-00-615-804-A - Decontamination of the Environmental Control System (ECS) when the Ambient Air Temperature is below 24 deg.C. (APU)

MECH | AMM

** ON A/C FSN ALL

TASK 21-00-00-615-804-A
Decontamination of the Environmental Control System (ECS) when the Ambient Air Temperature is below 24 deg.C. (APU)

WARNING: BE CAREFUL WHEN YOU USE CONSUMABLE MATERIALS. OBEY THE MATERIAL MANUFACTURER'S INSTRUCTIONS AND YOUR LOCAL REGULATIONS.

1. Reason for the Job
To decontaminate the ECS if oil has gone into it from the APU.

NOTE: This procedure must only be done after the source of the contamination has been repaired.

2. Job Set-up Information

A. Fixtures, Tools, Test and Support Equipment

REFERENCE	QTY	DESIGNATION
** ON A/C FSN 101-200		
No specific	AR	BLANKET - HEAT ISOLATION
No specific	AR	COVER - PROTECTION
** ON A/C FSN ALL		
No specific	1	HOT AIR BLOWER OPERATING 40 DEG C (104 D
No specific	AR	SAFETY CLIP - CIRCUIT BREAKER

B. Consumable Materials

REFERENCE	DESIGNATION
004BC1	Aqueous Cleaner-Aircraft Exterior Pressure Spraying -
089BB1	Non-Aqueous Cleaner - Petroleum Based -
145BA1	Textile-Lint free Cotton -

C. Work Zones and Access Panels

ZONE/ACCESS	ZONE DESCRIPTION
191ZB, 193BB	

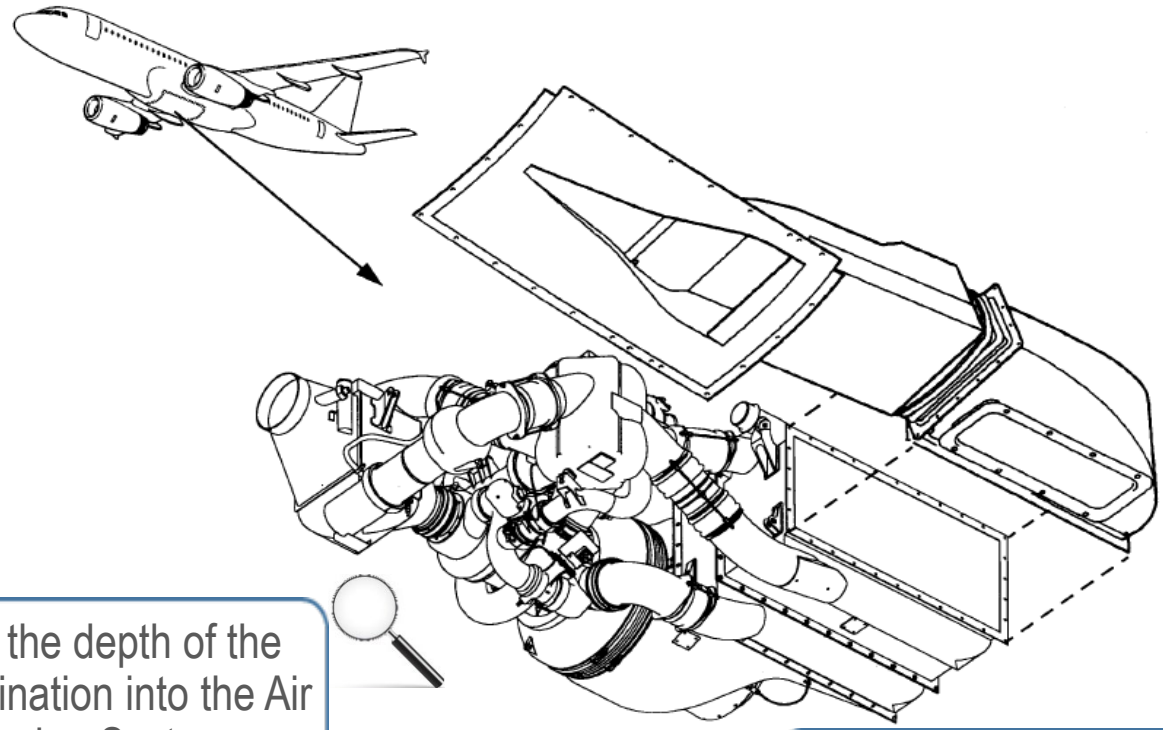
D. Referenced Information

ICP Task 1

CERTIFICATE OF TASK / INSPECTION COMPLETION:

CERTIFIES THAT THE TASK / INSPECTION HAS BEEN COMPLETED TO THE REQUIRED STANDARDS AND SUPPORTS THE FINAL MAINTENANCE RELEASE / CERTIFICATE OF RELEASE TO SERVICE

Page 1 of 15
PRINT DATE: Aug 28/2019



Assess the depth of the contamination into the Air Conditioning System



Components replacement and bleed ducts cleaning

High complexity and time to perform the recommended AMM task for Decontamination of the ECS

2. Cabin Air Quality Troubleshooting

Test and Release to Service

TEST

- Engine Run Up/APU on Ground
- Different Bleed and Pack configuration for smell identification at Cabin



RELEASE TO SERVICE

- No smell identification
- Put the Aircraft back in-service operation for flight

TAP PORTUGAL

Sheet *(Folha)* 1 of *(de)* 1

MAINTENANCE RELEASE *(Declaração de Aptidão para o Voo)*

☐ Check here in case of test flight *(Assinalar aqui em caso de voo de ensaio)*

AIRCRAFT *(Aeronave)*

MANUFACTURER *(Fabricante)*	MODEL *(Modelo)*
AIRBUS	A330-941
SERIAL NO. *(Nº. de Série)*	NATIONALITY & REGISTRATION MARKS *(Nacionalidade e Matrícula)*
01897	PORTUGUESA CS-TUE
FLIGHT HOURS SINCE NEW *(Total de Horas de voo)*	CYCLES SINCE NEW *(Total de Ciclos)*
729:43	91

CUSTOMER/OPERATOR *(Cliente/Operador)*

NAME *(Nome)*	ADDRESS *(Morada)*
TAP PORTUGAL	AEROPORTO DE LISBOA

THE AIRCRAFT ABOVE IDENTIFIED WAS INSPECTED AND REPAIRED OR MODIFIED, EXCEPT AS OTHERWISE SPECIFIED, IN ACCORDANCE WITH PART 145 AND, IN RESPECT TO THE WORK PERFORMED, IS CONSIDERED READY FOR RELEASE TO SERVICE. (*A aeronave acima identificada foi inspeccionada e reparada ou modificada, excepto se de outra forma especificado, de acordo com a PARTE 145 e, relativamente aos trabalhos realizados, é considerada aprovada para serviço*)

DESCRIPTION OF WORK PERFORMED (*Descrição do trabalho efectuado*):

A1.1 Check; EO's, RTR's and NR's.

PERTINENT DETAILS OF THE REPAIR ARE ON FILE AT THIS MAINTENANCE ORGANIZATION UNDER EVENT No. (O processo documental com os detalhes dos trabalhos efectuados encontra-se arquivado nesta Organização de Manutenção, sob o nº do evento): **AV 103639**

FOR SPECIAL REMARKS, INCLUDING DEFERRED ITEMS SEE 11 ATTACHED SHEETS, TO THIS ORIGINAL CERTIFICATE

(*As condições especiais em que é emitida esta declaração, incluídos itens diferidos, estão indicadas nas folhas anexas ao certificado original*)

DATE *(Data)*: 20 de agosto de 2019

SIGNATURE AND PRINTED NAME OF AUTHORISED PERSON BY QUALITY ASSURANCE DEPARTMENT:

(*Assinatura e nome legível de uma pessoa autorizada pela Direcção da Qualidade*):

TAP MA 726

Sig (*Ass*): Name (*Nome*):

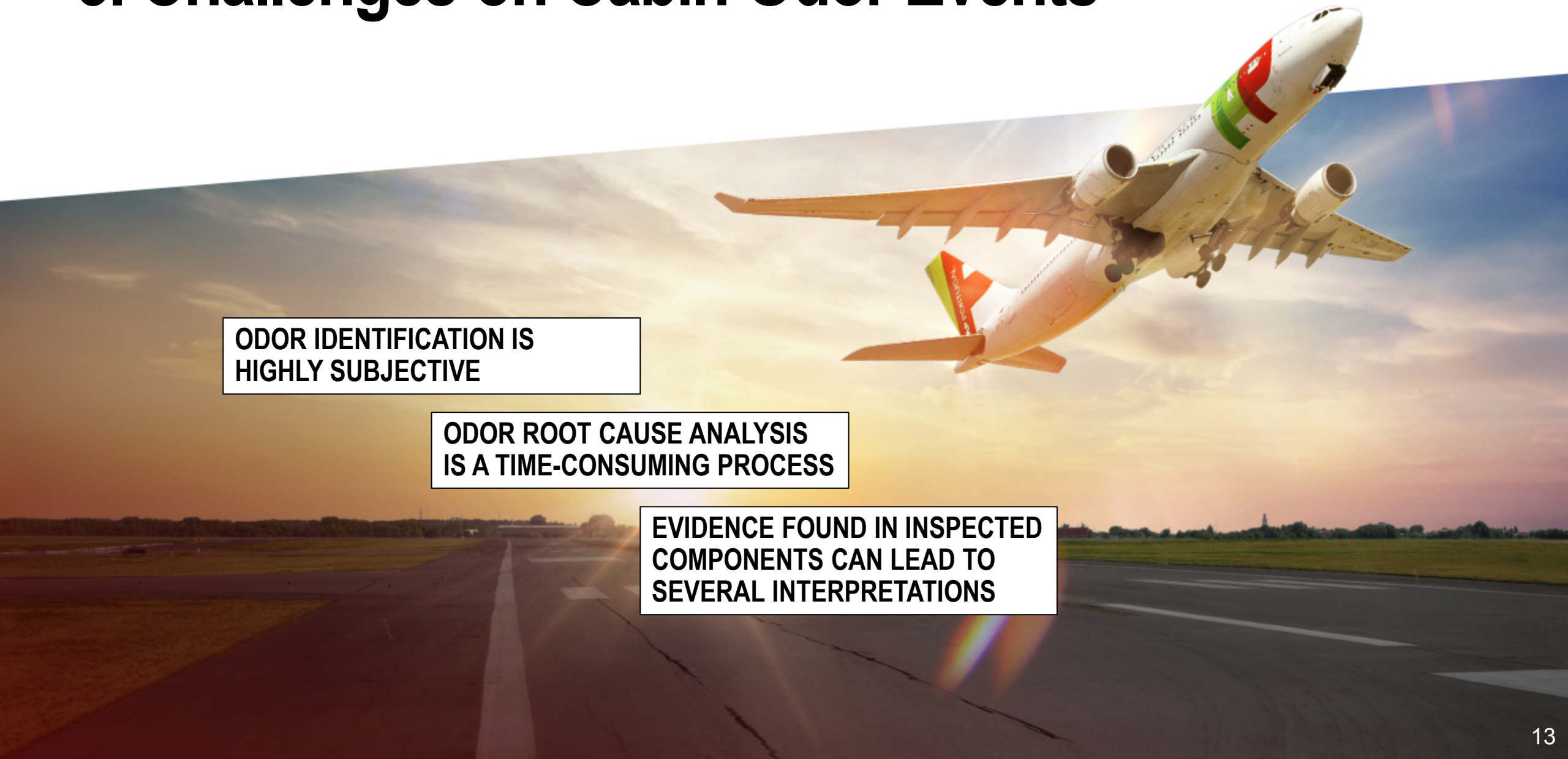
TAP PORTUGAL PART - 145 APPROVAL CERTIFICATE NO. PT.145.001

Maintenance & Engineering
Quality Assurance Department
P. O. Box 50194
1704-801 LISBOA - Portugal

Tel. No. 351 21 8416204
Fax No. 351 21 8415775
SITA Code LISMVTP
Telex 12231 TAP LIS P

TAP MOD ME 110 REV. 7, 26 NOV 2009

3. Challenges on Cabin Odor Events



ODOR IDENTIFICATION IS HIGHLY SUBJECTIVE

ODOR ROOT CAUSE ANALYSIS IS A TIME-CONSUMING PROCESS

EVIDENCE FOUND IN INSPECTED COMPONENTS CAN LEAD TO SEVERAL INTERPRETATIONS

4. Food for thought

- **Total Air filtration upstream of the cockpit and cabin**
  Issues, challenges related to maintenace tasks, parts replacement planning, costs, manpower, engine issues caused by oil leakage that could hardly be recognized/identified.

- **Identify the oil quantity from the pneumatic sources (Engine or APU) that causes oil smell at cabin**
  Measure assertively the cause/effect.

- **Predictive maintenance**
  Filtration efficiency after any oil odor event. How will the system filtration behave? Filters condition, proactive or reactive replacement?

- **Business case**
  Filtration benefits vs required budget for new filtration solutions.

- **AOG**
  Logistics challenge - Increased components replacement and storage costs.


Our vision
LEANER and FASTER troubleshooting for an air FREE of contaminants
TAP
AIR PORTUGAL



Ricardo Pavia – TAP Maintenance & Engineering

Email: rpavia@tap.pt

Phone number: +351 969 358 515

MAINTENANCE & ENGINEERING

ECA
European Cockpit Association

A Breath of Fresh Air – ECA's view on Cabin Air Quality

Rudy Pont

International Aircraft Cabin Air Conference 2021
Online, 15 – 18 March 2021

European Cockpit Association (ECA)



- Created in **1991**
- **Representative body** of European pilots at EU level
- **40.000+** pilots
- National pilot associations in **33 EU states**

ECA
European Cockpit Association

Position on Cabin Air Quality

Cabin air contamination is **a known problem**
that can cause **serious short- and long-term health effects**
which may compromise flight safety.



ECA
European Cockpit Association

ANNEX III (PART-ORO)

SUBPART GEN: GENERAL REQUIREMENTS

SECTION 2 – MANAGEMENT

ORO.GEN.200 Management system

COMMISSION REGULATION (EU) No 965/2012 of 5 October 2012
"laying down technical requirements and administrative procedures related to air operations"
https://eur-lex.europa.eu/legal-content/EN/TXT/PDF%20uri=CELEX:02012R0965-20160825 (page 57)

(a) The operator shall establish, implement and maintain a management system that includes:

(1) clearly defined lines of responsibility and accountability throughout the operator, including a direct safety accountability of the accountable manager;

(2) a description of the overall philosophies and principles of the operator with regard to safety, referred to as the safety policy;

(3) the identification of aviation safety hazards entailed by the activities of the operator, their evaluation and the management of associated risks, including taking actions to mitigate the risk and verify their effectiveness;

(4) maintaining personnel trained and competent to perform their tasks;

(5) documentation of all management system key processes, including a process for making personnel aware of their responsibilities and the procedure for amending this documentation;

(6) a function to monitor compliance of the operator with the relevant requirements. Compliance monitoring shall include a feedback system of findings to the accountable manager to ensure effective implementation of corrective actions as necessary; and

(7) any additional requirements that are prescribed in the relevant Subparts of this Annex or other applicable Annexes.

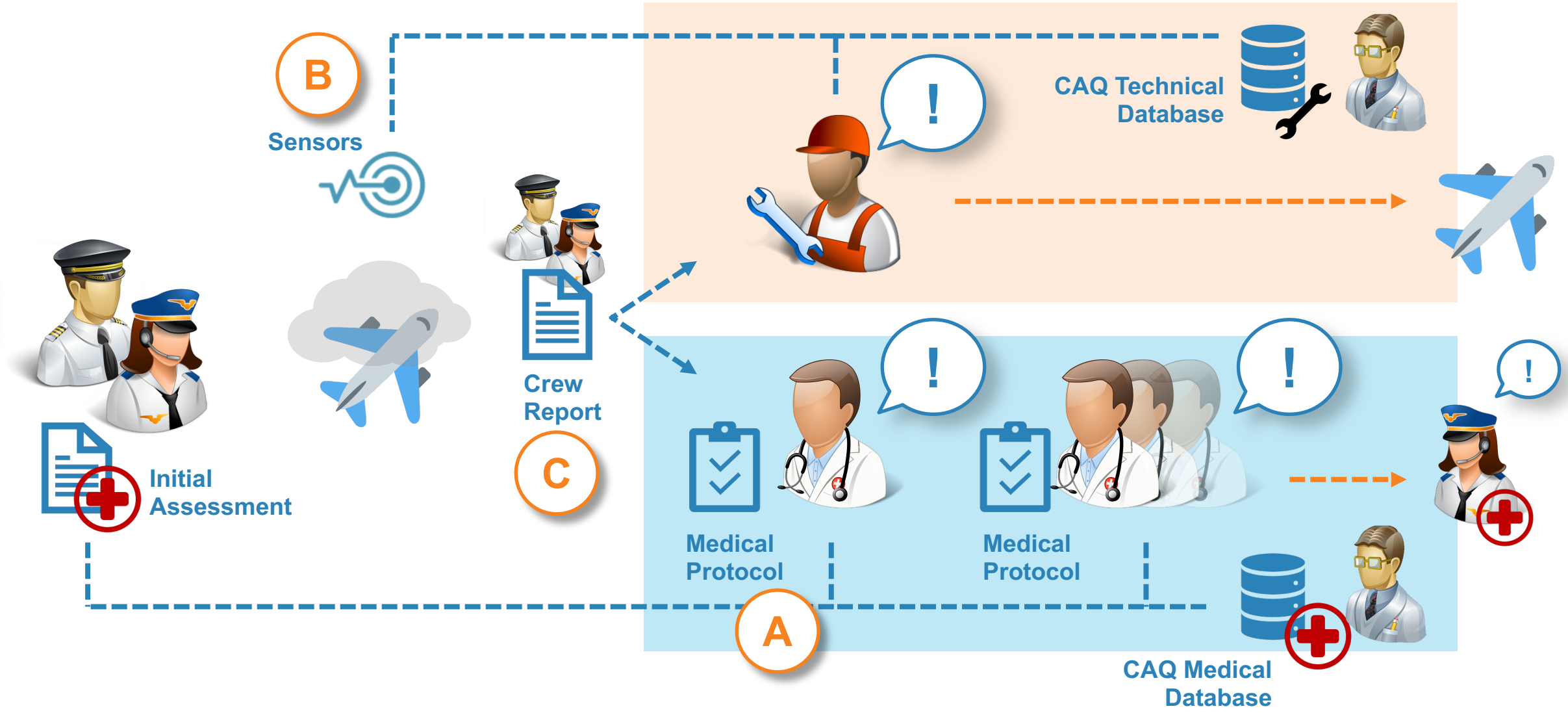
(b) The management system shall correspond to the size of the operator and the nature and complexity of its activities, taking into account the hazards and associated risks inherent in these activities

ECA
European Cockpit Association

Currently...



ECA
European Cockpit Association



ECA
European Cockpit Association

Position on Cabin Air Quality



A Need for a clear **standardised medical protocol**

B **Need for action** by operators & manufacturers based on the current knowledge and technology (sensors, filters, oil components, etc)

C Need for **regulatory follow-up on training, awareness and reporting**

Long-term = Bleed-free aircraft design

ECA
European Cockpit Association

ACA

AVIATION CLEAN AIR

Cleaning the Air We Breathe in Flight

Jonathan Saltman

ACA Needle Point Bi Polar Ionization - **Air and Surface Purification System:** Pathogen Neutralization in Aircraft

International Aircraft Cabin Air Conference 2021

16 March, 2021

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Airborne and Ground Systems

ACA AVIATION CLEAN AIR
Cleaning the Air We Breathe in Flight

ACA *"Cleaning the air we breathe in flight"*

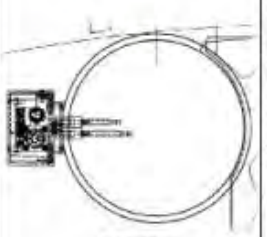
ACA technology is designed to purify and sanitized the air and surfaces on-board aircraft

The air and surface purification technology offered by Aviation Clean Air (ACA) is a proactive component that can be added to an existing environmental control system. ***The ACA component is not a filter system;*** filtration systems are passive and mostly ineffective as they only collect the allergens and pathogens that find their way back to them, located somewhere in the mechanical area of the aircraft.

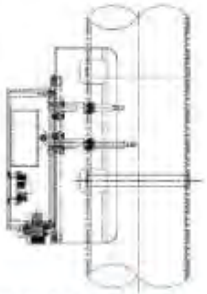
When air flows through the ECS ducts and into the cabin and cockpit, the ACA component removes existing odors, mold spores and allergens, proactively and rapidly. It also kills pathogens in the air and on surfaces where they sit throughout the aircraft interior including the cockpit, cabin, galley, lavatories and baggage areas. The ACA Component is effective floor to ceiling and wall to wall wherever the conditioned air reaches.

The component removes new odors caused by fuel emissions, as well as other VOCs generated by cooking, cleaning, stagnant air, cigarette/cigar smoke and many other sources. The ACA Component kills pathogens including, but not limited to, the common cold, flu of all types and variations, Covid 19, MRSA, C. diff, E. coli, M. terrae, pneumonia, and polio. A side benefit is that the system also controls static electricity within the the aircraft interior too. The technology is 100% green and works by duplicating and accelerating nature's cleaning process, with nothing else added, and No Ozone. The benefits are noticeable to crew and passengers in just seconds.





Installed Views



Contact us for more information today!

TDavis@aviationcleanair.com

Tel: 248-505-6804

www.aviationcleanair.com

Mechanical Specifications

Dimensions : 7.02"L x 3.27"W x 5.56"
With probes extended
Enclosure: Anodized Aluminum (Sealed)
Electrode Material: Carbon Fiber
Weight: 1.34 pounds (607 grams)
Temp. Range: -65°C / -85°F to +85°C/+185°F

Electrical Specifications

Voltage: 28 VDC (Range 18-32 VDC)
Current: 150 mA
Power: 4.2 Watts
Connection Type: MIL-C-26482, Series 2
Connector: 8 pin - MS-3470-L12-8-P
Pinout: A= 28 VDC, B = DC Common, C= Chassis Ground, D = Dry Contact Status Contact, E = Dry Contact Status.
(F,G, & H not used)
Status: Continuity between pins D & E when unit is powered and no fault is present. If a fault occurs the Component is not powered, pins D & E will be open.

Testing

The ACA component has been fully tested and meets and/or exceeds requirements of RTCA DO-160.

The ACA component environmental condition and tests are applicable to all airborne vehicles both Fixed Wing and Rotary aircraft platforms.

Application

The ACA component can be installed in pressurized or non-pressurized environments up to 55,000 Ft Alt

STC's

Certification for numerous aircraft and helicopter, types and models are now available for installation of the ACA systems.

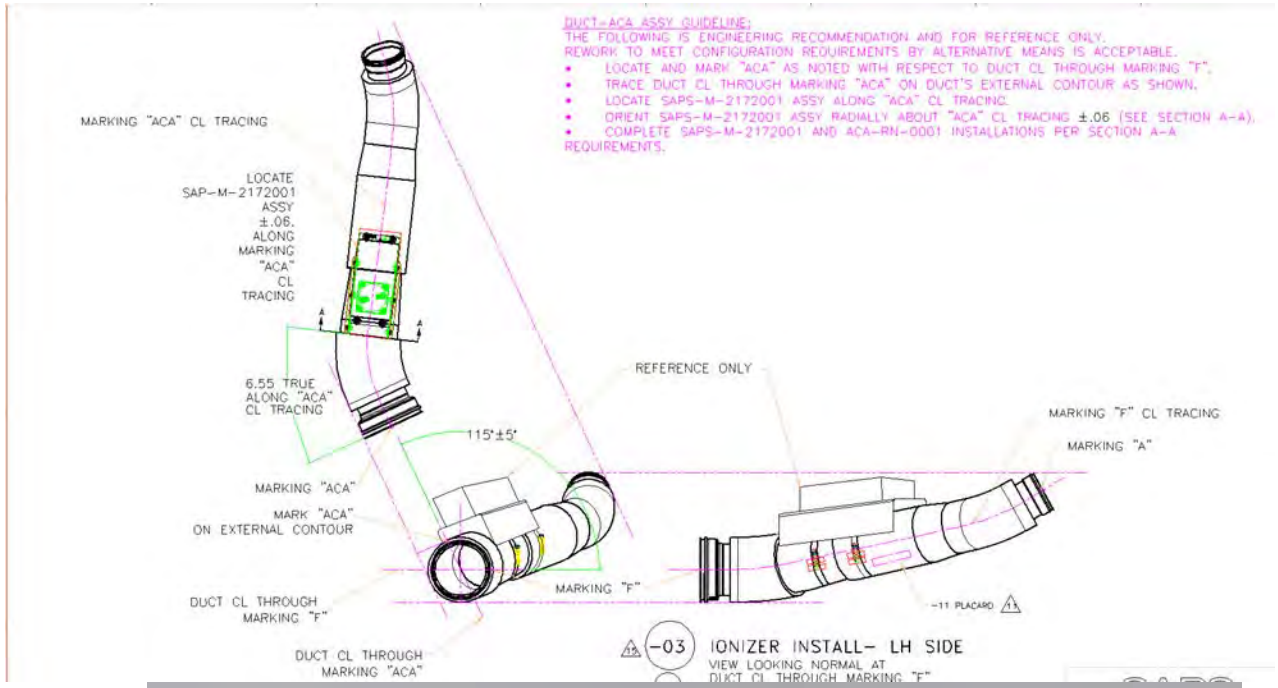
FAA PMA - 2017
Design and Utility Patents with others Pending

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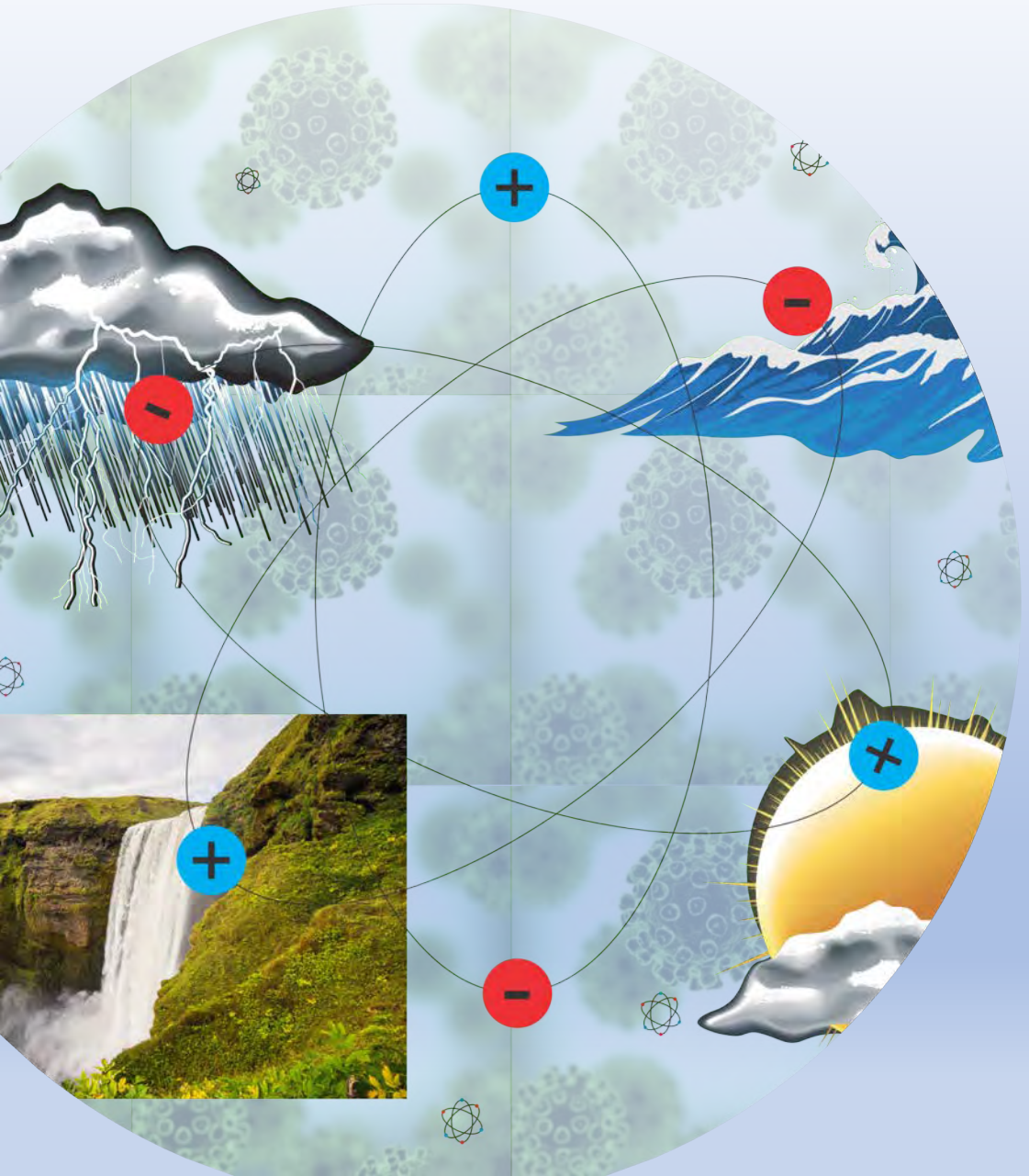
Over 60 STC's issued/in process for the ACA Airborne System installation







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HOW IONS ARE CREATED NATURALLY

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HOW IT WORKS

Ion unit creates positive and negative ions.

The ions are distributed throughout the aircraft cabin

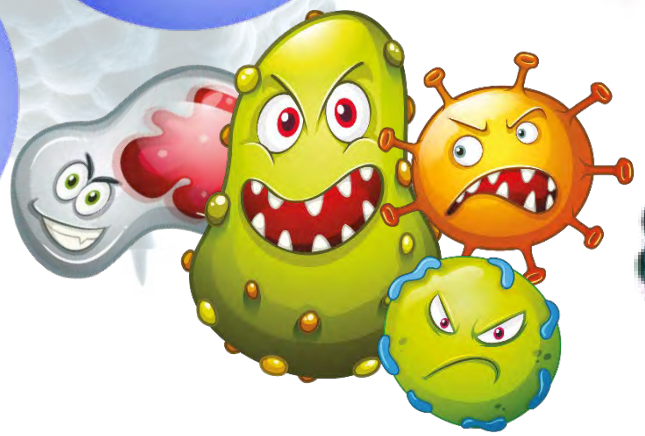
The ions surround harmful pathogens

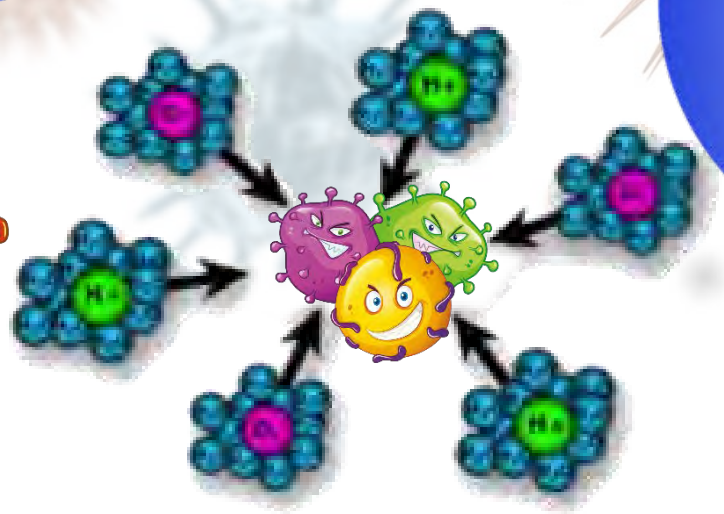
Hydrogen bonds are severed by a reaction that takes place on the cell's surface.

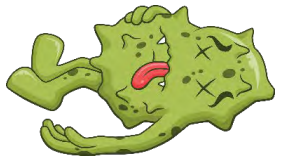
Without these hydrogen bonds, the pathogen will not be able to mutate, grow, nor reproduce, and will quickly die.







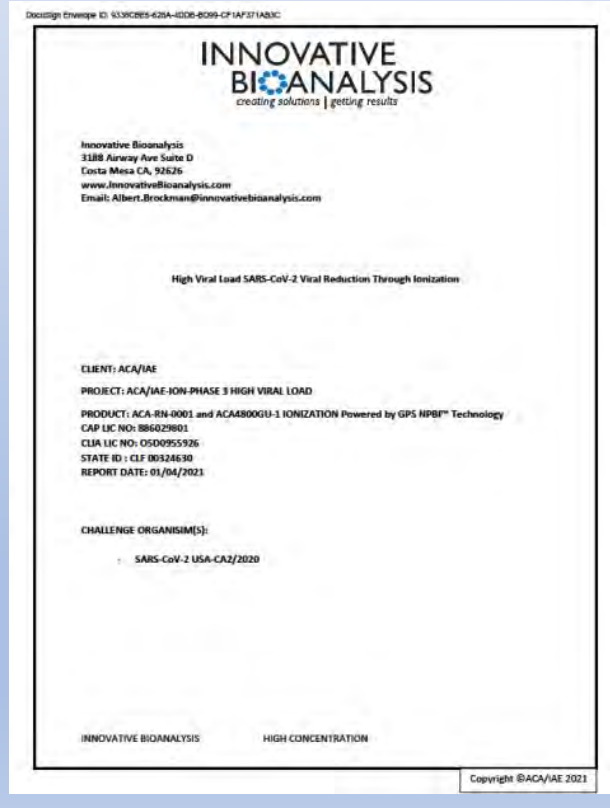




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The ACA System has been successfully verified to neutralize all pathogens tested



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Costa Mesa CA, 92626
www.InnovativeBioanalysis.com
Email: Albert.Brockman@innovativebioanalysis.com

High Viral Load SARS-CoV-2 Viral Reduction Through Ionization

CLIENT: ACA/IAE
PROJECT: ACA/IAE-ION-PHASE 3 HIGH VIRAL LOAD
PRODUCT: ACA-RN-0001 and ACA4800GU-1 IONIZATION Powered by GPS NPBI™ Technology
CAP LIC NO: 886029801
CLIA LIC NO: 05D0955926
STATE ID : CLF 00324630
REPORT DATE: 01/04/2021

CHALLENGE ORGANISIM(S):

- SARS-CoV-2 USA-CA2/2020

INNOVATIVE BIOANALYSIS HIGH CONCENTRATION

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SARS-Covid 19



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Costa Mesa CA, 92626
www.InnovativeBioanalysis.com
Email: Albert.Brockman@innovativebioanalysis.com

Influenza A & B Viral Reduction Through Ionization

CLIENT: ACA/IAE
PROJECT: ACA/IAE-ION-VIRAL-02
PRODUCT: ACA-RN-0001 and ACA4800GU-1, Powered by GPS NPBI™ Technology
CAP LIC NO: 886029801
CLIA LIC NO: 05D0955926
STATE ID : CLF00324630

REPORT DATE: 11/18/2020

CHALLENGE ORGANISIM(S):

- Influenza A - A/Wisconsin/67/2005 (H3N2)
- Influenza B - B/New York/1055/2003

INNOVATIVE BIO ANALYSIS INFLUENZA Page 1 of 13

Influenza A&B



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Email: Albert.Brockman@innovativebioanalysis.com

Methicillin Resistant S. Aureus Reduction Through Ionization

CLIENT: ACA/IAE
PROJECT: ACA/IAE-ION-MRSA-01
REPORT NUMBER: ACA/IAE-ION-MRSA-01
PRODUCT: ACA-RN-0001 and ACA4800GU-1, Powered by GPS NPBI™ Technology
CAP LIC NO: 886029801
CLIA LIC NO: 05D0955926
STATE ID: CLF 00324630

REPORT DATE: 01/04/2021

CHALLENGE ORGANISIM(S):

- Methicillin Resistant Staphylococcus Aureus

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MRSA



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Email: Albert.Brockman@innovativebioanalysis.com

ASPERGILLUS NIGER Reduction Through Ionization

CLIENT: ACA
PROJECT: ACA/IAE-ION-FUNGI-01
REPORT NUMBER: ACA/IAE-ION-FUNGI-1
PRODUCT: ACA-RN-0001 and ACA4800GU-1, Powered by GPS NPBI™ Technology
CAP LIC NO: 886029801
CLIA LIC NO: 05D0955926
STATE ID: CLF 00324630

REPORT DATE: 11/20/2020

CHALLENGE ORGANISIM(S):

- Aspergillus Niger

1

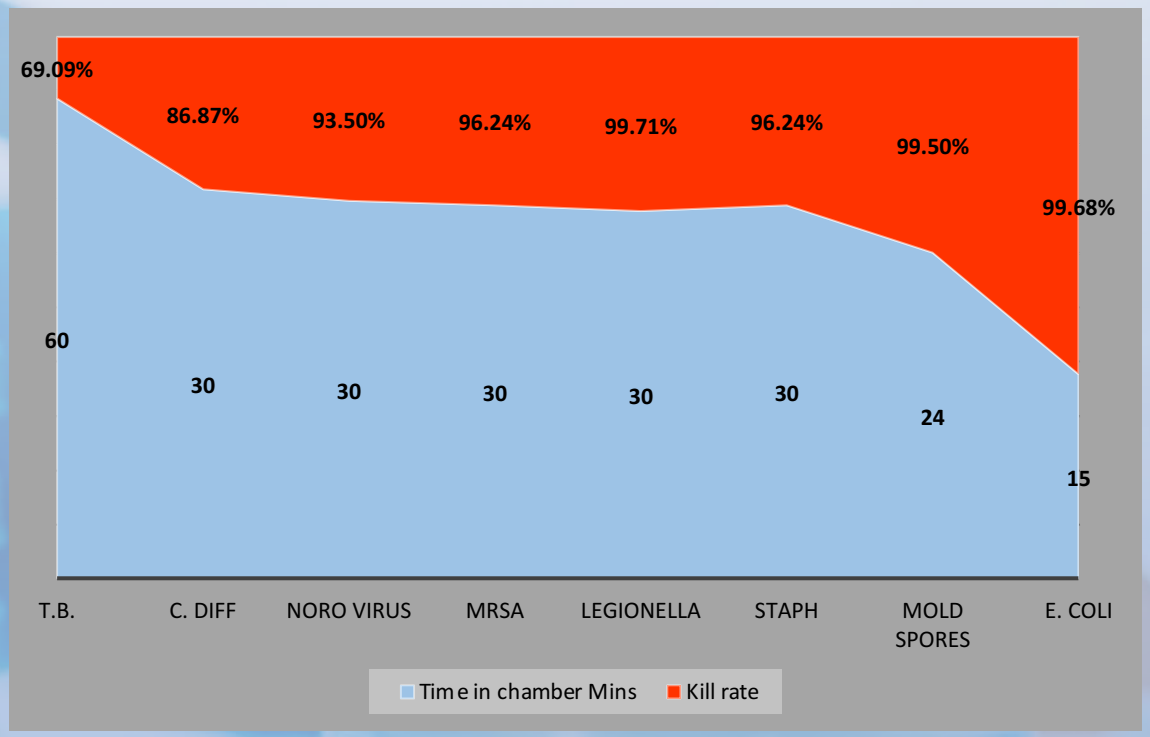
Aspergillus

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	Minutes in Chamber	Kill rate
T.B.	60	69.09%
C. diff	30	86.87%
Noro Virus	30	93.50%
MRSA	30	96.24%
Legionella	30	99.71%
Staph	30	96.24%
Mold Spores	24	99.50%
E. coli	15	99.68%





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Chemical Compounds Ionization Can Control

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CHEMICAL	FORMULA	Electron Volt
Xylene*	C_8H_{10}	7.89
Styrene*	C_8H_8	8.46
Methyl Ethyl Ketone*	C_3H_8O	9.52
Ammonia*	NH_3	10.07
Acetaldehyde*	CH_3CHO	10.23
Ethyl Alcohol*	C_2H_5OH	10.48
Formaldehyde*	CH_2O	10.88
Oxygen	O_2	12.07
Corona tubes require >12.07 to break down the dielectric		

NPBI

DIELECTRIC/CORONA DISCHARGE TUBE > 12.07eV

* Typical contaminants of concern as contained within ASHRAE 62.1

- Electron Volt Energy greater than 12Ev, creates ozone (O_3)

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WHY ION TECHNOLOGY?

The ACA/IAE system operates under 12.0eV, so our system does NOT produce any Ozone (O3), or any harmful gases or chemicals.
As such, our system is not harmful to the aircraft, the interior, the people on board,
or any food on board.





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WHY NOT HEPA ALONE?

- HEPA filters are great at removing airborne contaminates and removing contaminates from going through their filters. They are ineffective for surface contaminates and have no effect on static contaminants.

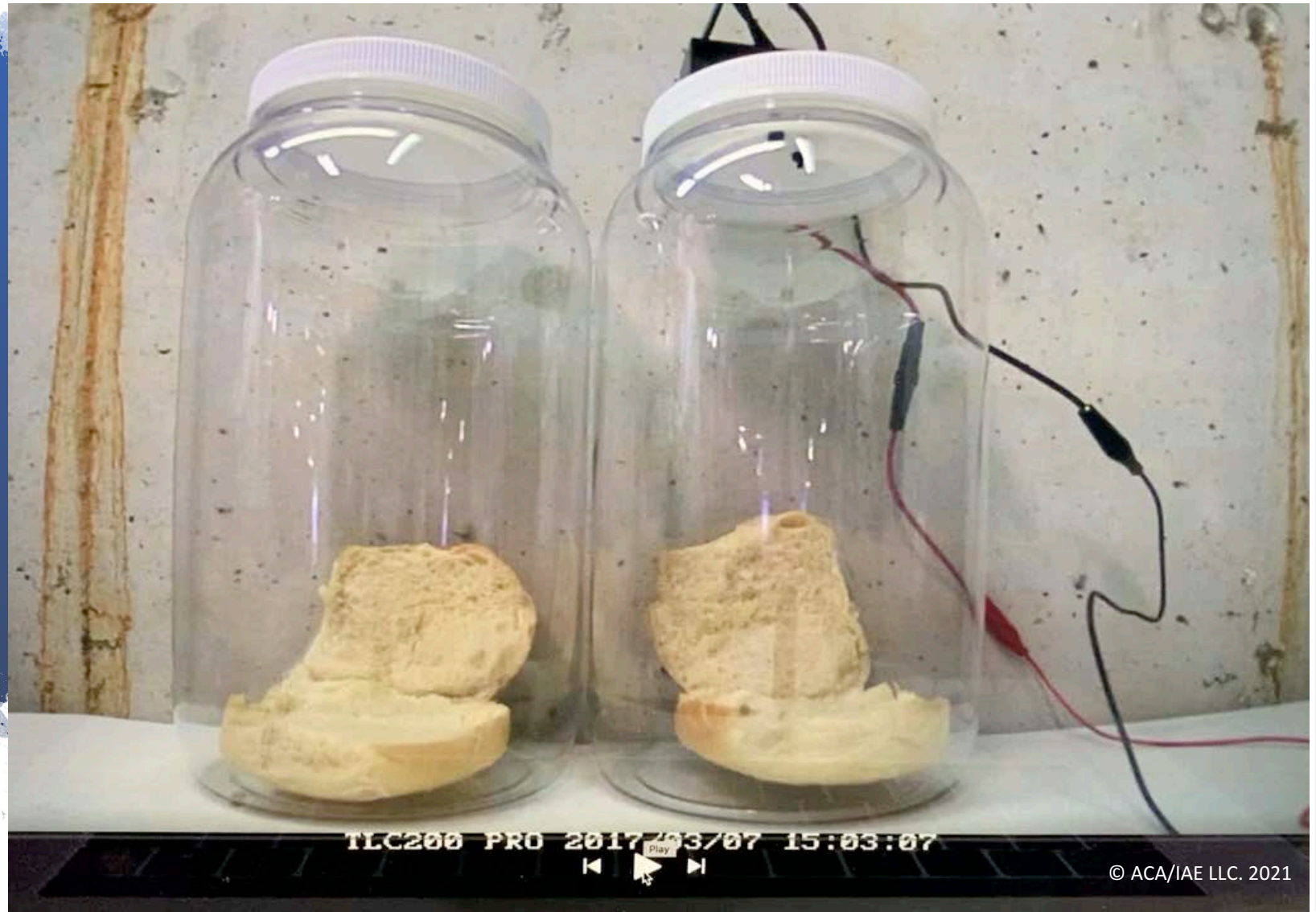
- Our system neutralizes pathogens. Our system keeps particulates from the breathing zone and reduces the particulate count within seconds allowing the HEPA filters to do a more effective job.

- The ACA/IAE system was first STC's on Gulfstream's which have the highest fresh air refresh rate in the industry, and their independent testing has proven that our system neutralizes pathogens in their cabin.

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Time Lapse of Bread/Mold Ion Test

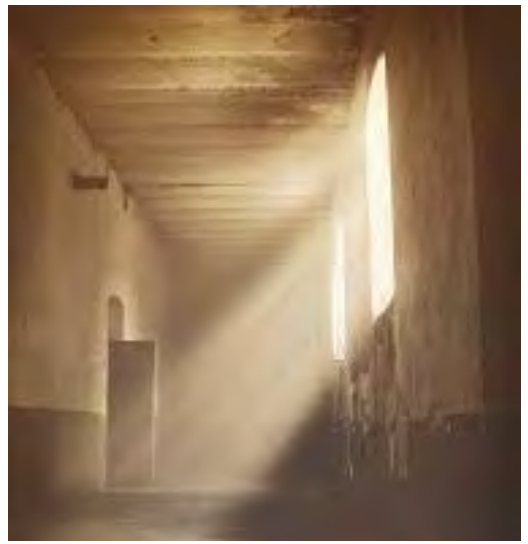


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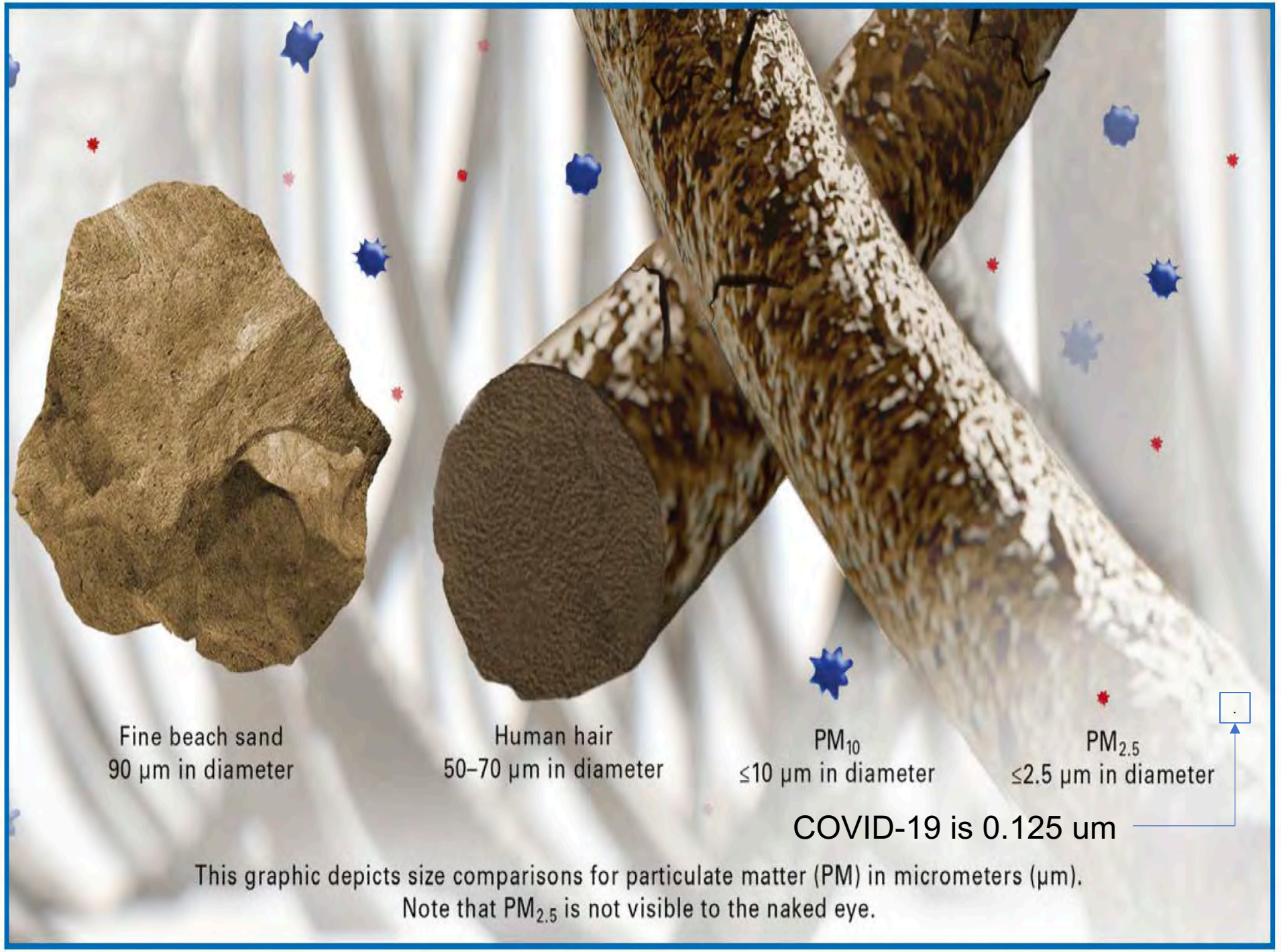
HOW PARTICLES ARE CREATED

- A person sitting or stopped generates about 100,000 particles per cubic ft.
- Sitting down or standing up generates about 2,500,000 particles cubic ft.
- Walking generates about 10,000,000 particles per cubic ft.
- Horseplay generates about 30,000,000 particles per cubic ft.
- Grinding, sweeping, welding adds billions of particles per cubic ft.
- Two surfaces rubbing generate billions of particles per cubic ft.

There are over 18 Million particles in 1 cubic ft of air



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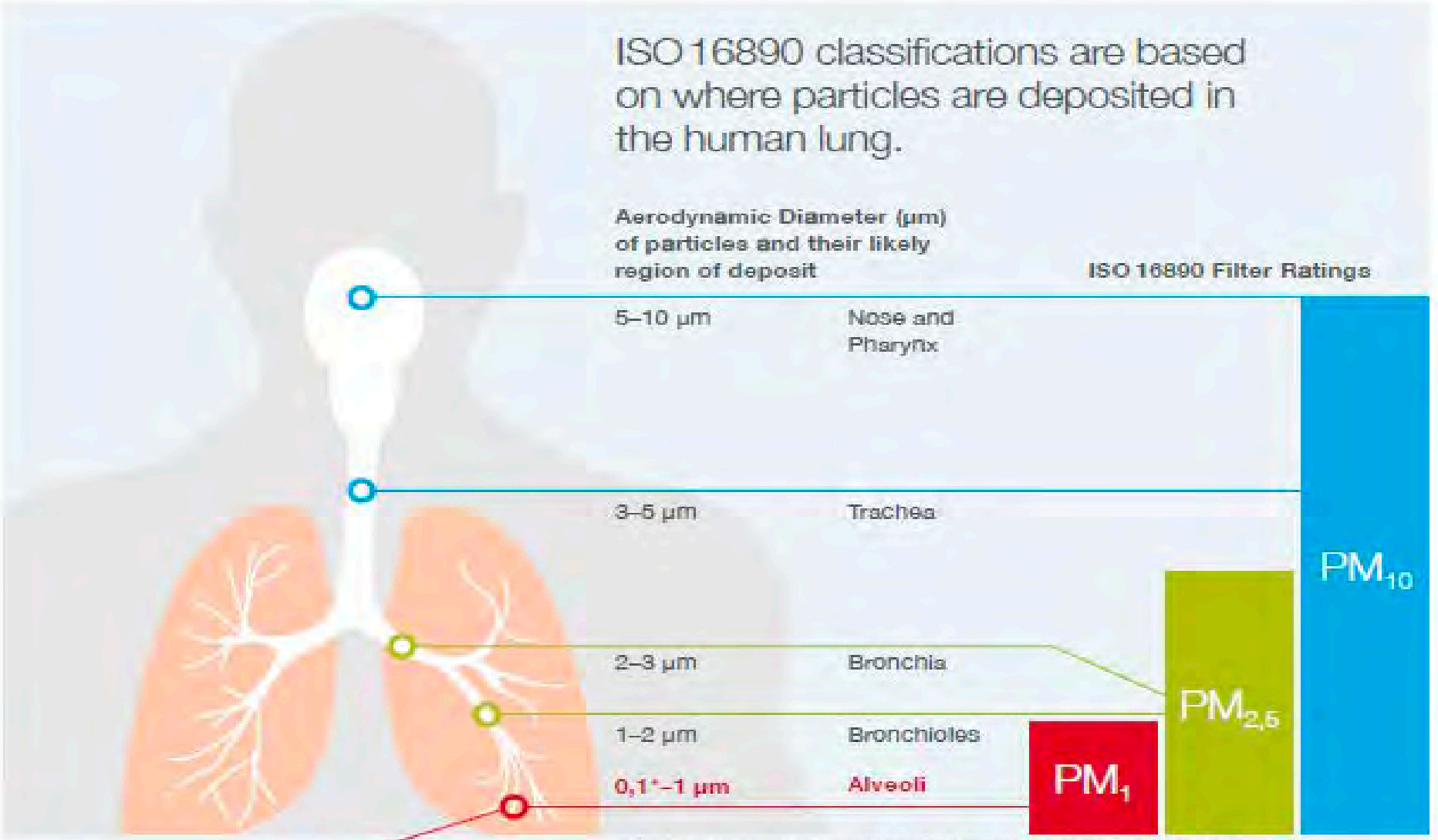
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Particle Agglomeration Test



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PM_1 – The Smaller the More Dangerous!

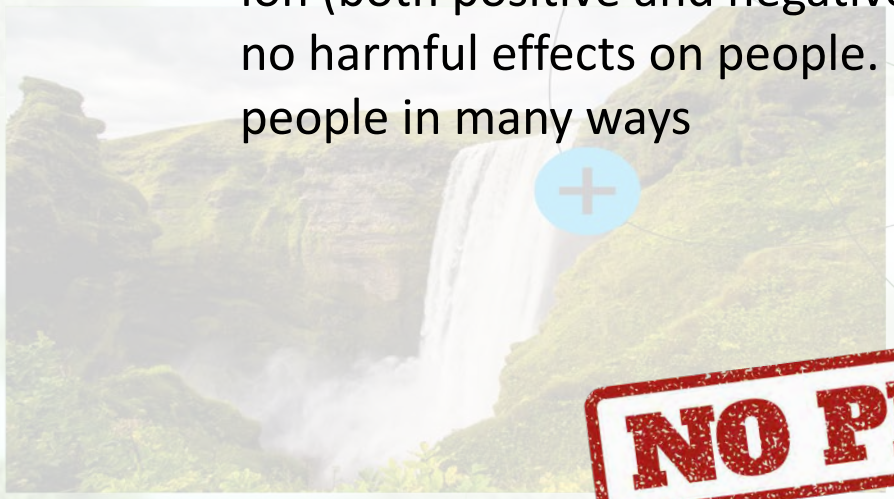
A variety of studies are focusing on the health effects of PM1 particles:

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CHEMICAL FREE

- There are many risks and side effects of chemicals, some of which are unknown.
- The ACA/IAE system does not use chemicals and will not create any adverse effects to the aircraft or any occupants in the aircraft.
- Ion (both positive and negative) have been widely researched to show there are no harmful effects on people. In fact they have been shown to be beneficial to people in many ways





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MILITARY CUSTOMERS

- **Special Air Missions Joint Base Andrews**
- Ramstein Air Force Base
- 435th Contingency Response Group
- Hickam Air Force Base
- Fleet Logistics Support Squadron JBA
- 909th AMU
- USAF 113 WG
- 932 MXG
- NORAD
- US Navy
- AIRSTA Washington
- 673 CONS/PKC
- NAS JRB Fort Worth
- 86 MXG/AMXS/CCR
- 718 AMXS/MXAW/909th AMU
- USAF 113 WG
- Fleet Logistics Support Squadron 57 (VR-57)
- Fleet Logistics Support Squadron 51 (VR-51)
- Fleet Logistics Support Squadron VR-56 Supply
- M1 Support Services
- US Government - 89th Airlift Wing
- US Marines
- US Air Force
- US Army
- March ARB
- 374th AMXS/MXABS Yokota AB, Japan
- 718 AMXS/909th AMU KC-135 Kadena Air Base, Japan
- 15th Operations Group
- Joint Base Pearl Harbor-Hickam
- Camp Lemonnier, Republic of Djibouti
- JBPHH
- 154 Civil Engineer Squadron
- 774 EAS/AFE NCOIC
- 718 AMXS / 909 AMU
- 435th Security Forces Squadron
- Eielson Air Force Base

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Key Points

- ACA Is the only proactive system available. All other systems are passive.
- ACA Is the only proactive continuous cleansing system available.
- ACA Kills pathogens in the space on surfaces and in the air in moments (not hours or days).
- ACA System is automatic.
- ACA Requires no scheduled maintenance.
- ACA Installs quickly and seamlessly in any ECS system.
- ACA Produces no harmful by products.
- ACA Uses no chemicals. ACA produces no chemicals or harmful by-products.
- ACA Is not a filtration system.
- ACA Is a replication and acceleration of Nature's natural Cleansing process with nothing else added.
- ACA Benefits are noticeable to the occupants in moments if not seconds.

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THANK YOU

Contact: Jonathan Saltman
Email: Sales@AviationCleanAir.com
Phone: (562) 253-5020

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Routes of Aircraft Cabin Air Contamination from Engine Oil, Hydraulic and Deicing Fluid

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The paper was presented at the International Aircraft Cabin Air Conference 2021 (ACA2021), Online, 15-18 March 2021, https://www.AircraftCabinAir.com

Abstract: *Purpose: This paper discusses potential contamination of the air in passenger aircraft cabins. It gives an overview of cabin air contamination basics. It further names possible contamination sources and possible routes of contamination. – Methodology: Evidence follows from a review of material found on the Internet and from the documentation of a visit to an aircraft recycling site. Parts were retrieved at the site and investigated later with more time. – Findings: Jet engine seals leak oil in small quantities. Metallic nanoparticles are found in the oil and have been detected in human fatty tissue of aviation workers. It has been observed that the potable water on board can also be contaminated. Oil traces have been found in bleed ducts, air conditioning components, and in air conditioning ducts. Deicing fluid and hydraulic fluid can find their way into the air conditioning system via the APU air intake. Fuel and oil also leak down onto the airport surfaces. These fluids can be ingested by the engine from the ground and can enter the air conditioning system from there. Entropy is the law of nature that states that disorder always increases. This is the reason, why it is impossible to confine engine oil and hydraulic fluids to their (predominantly) closed aircraft systems. This is why engine oil with metal nanoparticles hydraulic fluids, and deicing fluids eventually can go everywhere and finally into the human body. – Research Limitations: No measurements have been made. – Practical Implications: Awareness and prevention of contaminated cabin air can protect passengers and crew. – Social Implications: The exposure of contaminated cabin air provides a basis for a general discussion and shows that people should be alerted and need to act. New technologies need to be implemented such as a bleed free architecture. – Originality: This paper shows many original images of contaminated parts and air ducts between engine compressor and cabin air outlet. Own observations are combined with similar observations found in literature and online. The collected evidence is visualized in a diagram showing the routes of possible aircraft cabin air (and water) contamination.*

Key Words: *aircraft, passenger, cabin, engine, bearing, lubrication, oil, seal, compressor, hydraulic, deicing, fluid, bleed air, contamination, ventilation, APU, ingestion, air conditioning, entropy, fume event, CACE*

1. INTRODUCTION

Cabin air ventilation in passenger aircraft is done with outside air. At cruise altitude, ambient pressure is below cabin pressure. Hence, the outside air needs to be compressed before it is delivered into the cabin. The most economic system principle simply uses the air that is compressed in the engine compressor and taps some of it off as "bleed air". This principle is explained in [1] (German) and [2] (English). In the context of contaminated cabin air the background can be found in [3], [4], and [5]. Fig. 1 shows the contaminants and their routes into the cabin. The individual routes are explained below.

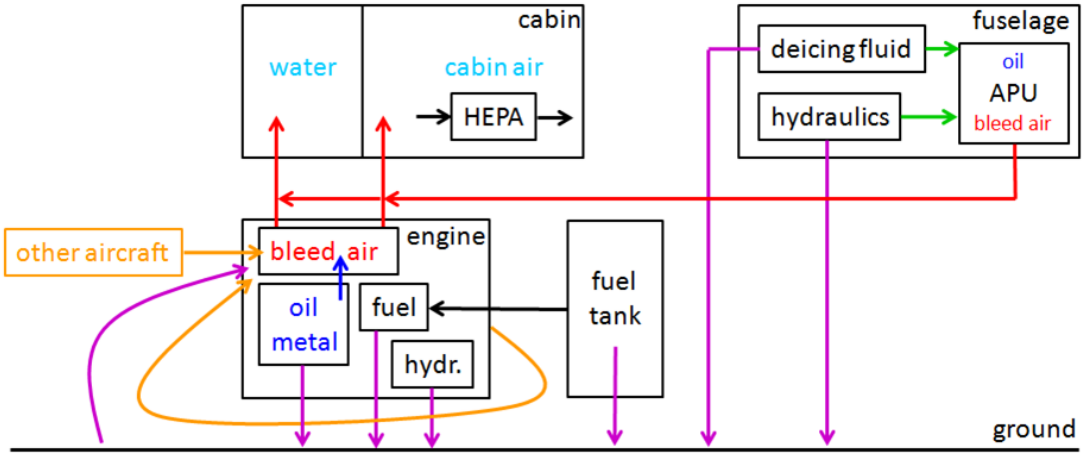


Fig. 1 - Contaminants and their routes into the cabin

Route in blue: Seals at the engine bearings leak by design (Chapter 2). The leaking oil includes metal nano particles (Chapter 3). The oil with metals finds its way into the engine compressor. The same holds for the APU.

Routes in green: Deicing fluid sprayed on the tail of the aircraft flows down along the surface of the aft fuselage and surrounds the air intake of the APU at the bottom of the fuselage. Hydraulic fluid leaks from the main landing gear bay and is directed along the outside of the fuselage, to the APU air intake. In this way deicing fluid and hydraulic fluid can enter the APU via its air intake (Chapter 4).

Routes in red: Oil and metal from the engines find their way via bleed air into the cabin (Chapter 3) and into the potable water (Chapter 3.1). Oil leaks also from the APU into the APU bleed air and into the cabin. In addition, deicing fluids and hydraulic fluids make their way via the APU bleed air into the cabin.

Routes in purple: Deicing fluids, hydraulic fluids, oil, and fuel (from the fuel tank or from the engine) drip on the ground. The engine ingests these liquids from the ground (Chapter 5). Once in the engine compressor, the liquids find their way via the bleed air into the cabin.

Routes in orange: Exhaust gases from other aircraft are ingested. In case of a strong tailwind on the ground or in case of reverse thrust at landing, the engine ingests its own exhaust. Contaminates find their way via the bleed air into the cabin.

HEPA filter: In the cabin, HEPA filter are part of the recirculation (Chapter 6). Standard HEPA filters cannot mitigate the problem of oil contamination.

2. JET ENGINE TECHNOLOGY AND RESULTS

The engine shaft is supported by lubricated bearings. Fig. 2 shows the location of the bearings in a jet engine and the position, where the bleed air is tapped off for cabin ventilation.

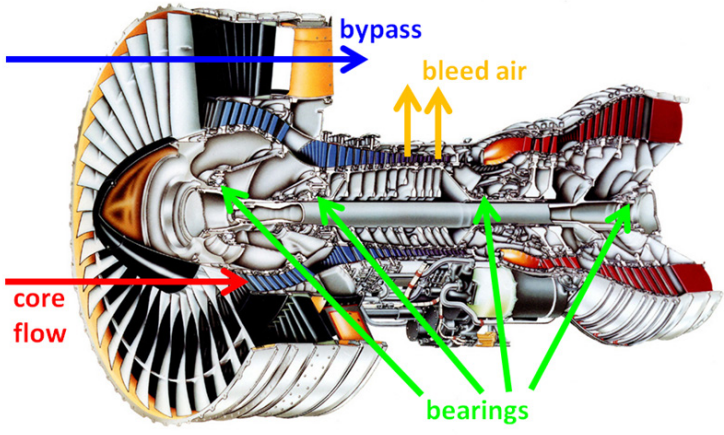


Fig. 2 - Engine bearings and bleed air (based on [6])

The bearings are sealed against the air in the compressor usually with labyrinth seals, shown in Fig. 3. Unfortunately, the jet engine seals leak oil by design in small quantities. Even more so, the seals leak oil in certain flight phases, when they are worn out, or in failure cases.

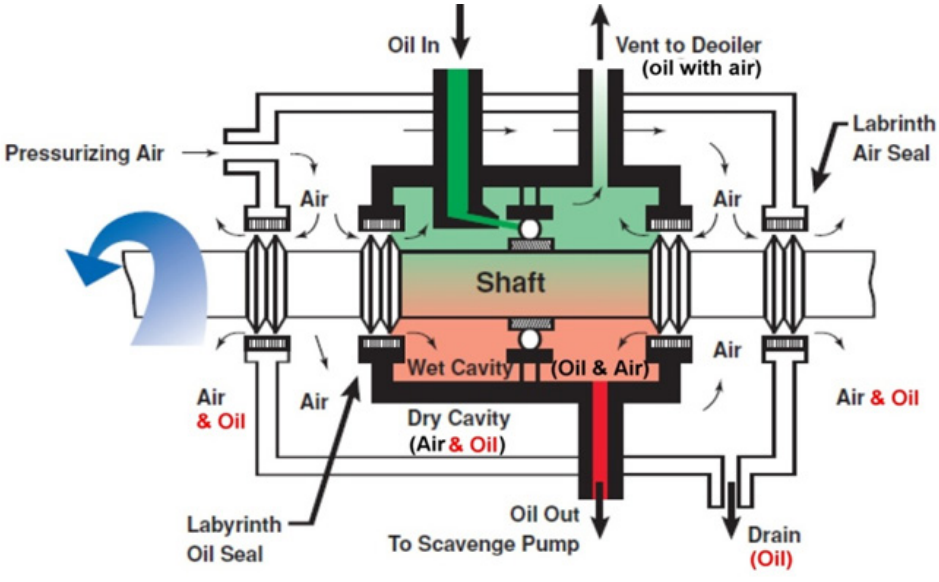


Fig. 3 - Lubrication and sealing of engine bearings (based on [7])

Even in normal operation, the engine seals leak small quantities of oil. This follows from Fig. 3 and these observations:

1. The "drain" discharges oil.
2. The "dry cavity" contains oil.
3. Air and oil leak from the bearing chamber into the air stream of the compressor and into the bleed air.

Accordingly, engines leak small amounts of oil by design. The oil with its toxic additives leaks into the compressor. It is pyrolized at the high air temperatures in the compressor leaving hundreds of organic substances behind some of which are toxic. Furthermore, the oil includes toxic metal nanoparticles – normal debris from the engine. These metal nanoparticles from the oil are finally found in the body of crew members as shown in the example of Fig. 4.

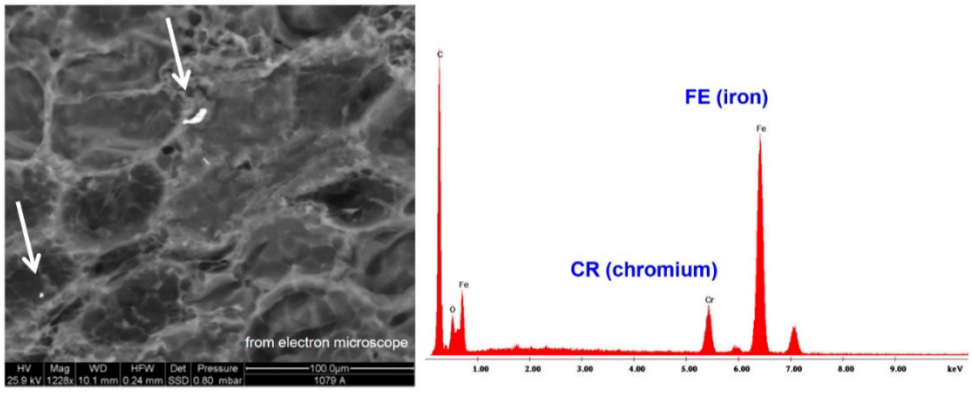


Fig. 4 - Left: High-magnification image (1228x) of human fatty tissue of a cockpit crew member showing a 10-micron (top) and a 1-micron (bottom, left) brighter-looking metal particle. Right: The EDS (Energy-Dispersive X-ray spectroscopy) spectrum analyzes the brighter-looking metal particles from the left picture, indicating carbon (C), iron (FE), chromium (CR) and Oxygen (O), hence a stainless-steel composition ([8], Analysis 8 of Table I, report written for client). The metal is probably debris from the engine transported with the oil into cabin and cockpit air

3. DISTRIBUTION OF ENGINE OIL WITH NANOPARTICLES

An alternative source for the compressed air is the Auxiliary Power Unit (APU). Like the aircraft's jet engine, it is a gas turbine, built much in the same way when it comes to bearings and seals. For this reason, also compressed air from the APU can get contaminated in the same way (see Fig. 3). Fig. 5 shows the route of the engine oil into the cabin via bleed air from the engines and compressed air from the APU.

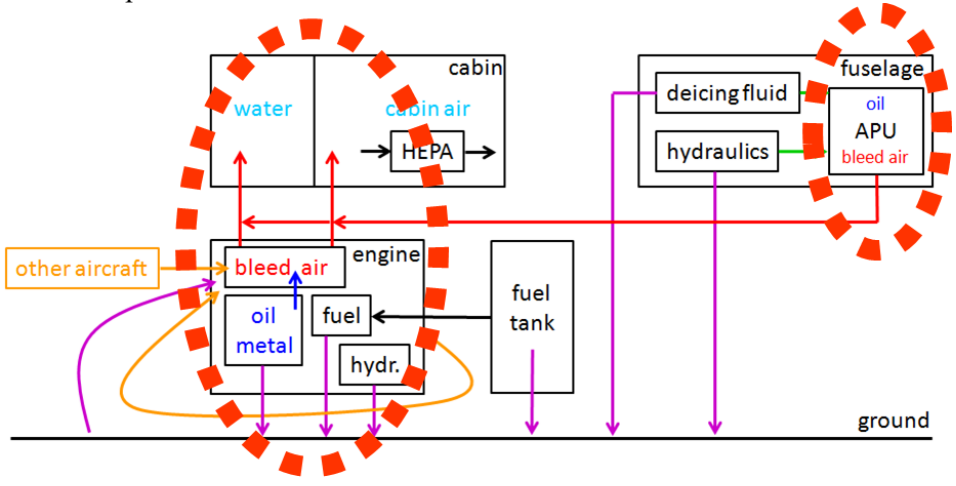


Fig. 5 - The route of engine oil into the cabin

The Fig. 6 to 9 show the inside of a cabin in a Cabin Air Contamination Event (CACE) due to engine oil after a technical fault.



Fig. 6 - 2010-09-17, US Airways US-432, Boeing 757-200. Maui-bound flight enroute overhead the Pacific diverted to San Francisco (1200 nm). More: [9]. Picture source: Video: https://youtu.be/AZqeA32Em2s



Fig. 7 - 2018-12-10, Indigo flight 6E-237, Airbus A320neo, Jaipur to Kolkata, India. The smoke was traced down to the engines (PW1127). This and more: [10]. Cause: Leakage of oil from the engine [11]. Picture source: Video: https://youtu.be/TO_FZ3L4yus

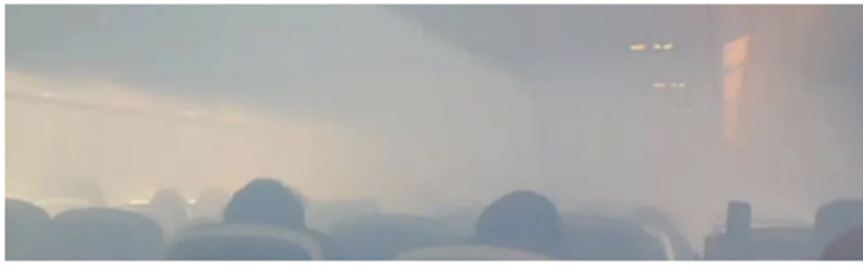


Fig. 8 - 2019-08-22, Hawaiian Airlines HA47, A321neo. Emergency landing and evacuation after smoke on board. Cause: Seal failure in left engine. Picture source: Glen Westenskow. This picture and more: [12]. More also on https://purl.org/cabinair/HA47

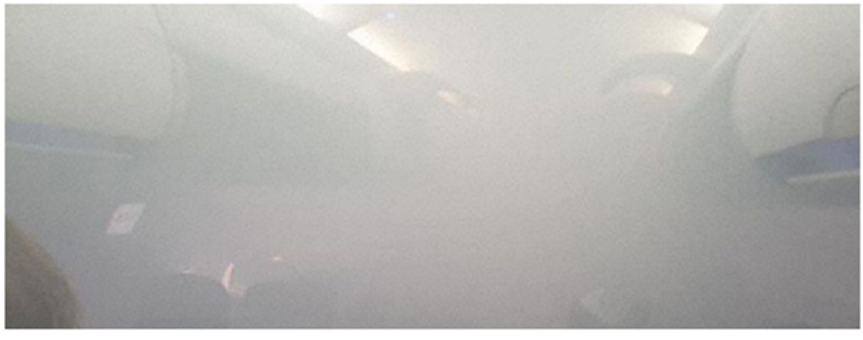


Fig. 9 - 2019-08-05, British Airways BA-422, Airbus A321. On a flight from London Heathrow to Valencia, the aircraft was descending towards Valencia when smoke appeared in the cabin. It followed an emergency evacuation. The aircraft remained 9 days in Valencia and was subsequently ferried to London. After a total of 31 days the aircraft returned back to service [13]. "It was found that no fire had occurred, but engine #2 (V2533, right hand) had lost all its oil. The engine was removed from the airframe and sent to the manufacturer for thorough inspection." This and more on: [14]. Picture source: Lucy Brown. Video: https://youtu.be/tFsN0h09gAI

3.1 Engine Oil in the Potable Water

Compressed air from the engine is also used to pressurize the potable water tanks on some aircraft like the Airbus A320 [15]. It has been observed that the potable water on board can also be contaminated. Potable water contaminated by bleed air on an Airbus A320, is shown in Fig. 10. It is the last water extracted from the tank before it is empty. This water is black, probably from engine oil residue.

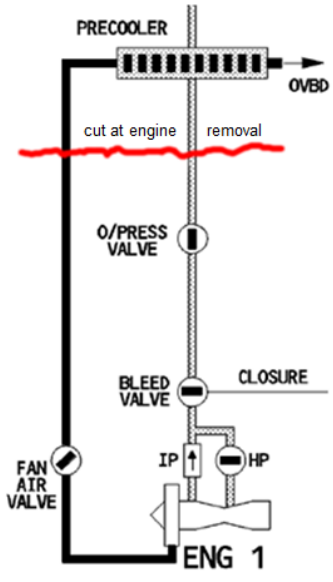


Fig. 10 - Potable water contaminated by bleed air on an Airbus A320. This is the last water extracted from the tank before it is empty. This water is black, probably from engine oil residue. Picture source is a Video: https://youtu.be/dlPOeudTTCI. The video is explained: On the A320 the potable water tank is pressurized with bleed air.

On the A320 also the hydraulic reservoirs are pressurized with bleed air. The bleed air presses on the free surface of the hydraulic fluid and gets as such in contact with it. The "mixture of hydraulic fluid vapor and bleed air" is connected via bleed lines with the potable water tanks. But flow of this mixture into the potable water tanks is unlikely:

- In flight, the "mixture of hydraulic fluid vapor and bleed air" would need to flow upstream and opposite sense through two check valves (which by design will not happen in larger quantity) to get into the bleed line for water pressurization.
- However, on the ground (without bleed pressure), the hydraulic fluid vapor and bleed air mixture can flow downstream(!) but would still need to flow opposite sense through two check valves (which by design will not happen in larger quantity) to get into the bleed line for water pressurization.

3.2 Engine Oil Colors Bleed Air Ducts



When an engine is taken off the aircraft, two air ducts become visible: the duct for the fan air and the duct for the bleed air. Fan air and bleed air ducts at the interface between engine and wing carry outside compressed air. Fig. 11 shows a diagram from the Airbus A320. The red line indicates the cut when separating the engine from the wing. The fan air is fresh outside air that has at best touched the fan blades (or the outlet guide vanes) on its way through the engine bypass.

Fig. 11 - Fan air and bleed air taken off a jet engine. The red line indicates where the fan air duct and the bleed air duct are separated, when the engine is taken off. The diagram is a simplification based on a diagram explaining the pneumatic system (ATA 36) in [16]

On the other hand, the bleed air is fresh outside air that has gone through the core of the engine. If everything were right, there should not be a difference depending on where the outside air gets compressed. Unfortunately, there is a difference. Bleed air is potentially contaminated with engine oil. This can be seen in Fig. 12. The fan air duct shows a normal metallic surface color, whereas the bleed air duct at the engine interface appears brown. The bleed air temperature at this point is about 300°C ... 400°C, the fan air is closer to ambient temperature. Metal on its own does not turn to a brown color when heated to 400°C. The only explanation with respect to the difference in the color of the two ducts is that the bleed air is covered by a brown residue. Confirmation comes from touching the surface. If not deposited in the duct, the substance causing the residue makes otherwise its way into the cabin. We know from engineering (Fig. 3) that jet engine seals leak oil by design. Therefore, the brown residue in the bleed air duct compared to the fan air duct is a confirmation that oil leakage takes place in the engine.



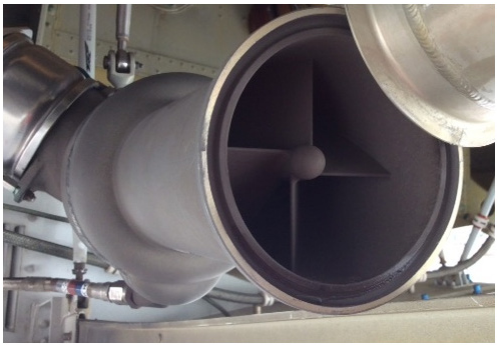
Fig. 12 - Bleed air duct with brown stain compared to a clean fan air duct on an Airbus A320

Ducting further downstream shows a black dry cover. The reason for the change in color seems to result from the different air temperatures: 400°C at engine outlet and 200°C further downstream behind the precooler. Fig. 13 shows a bleed air duct of a Boeing 737 with black oil residue inside.



Fig. 13 – Engine oil colors bleed air duct black (it is not just dark) from a Boeing 737. Picture source: Video: https://vimeo.com/groups/617439/videos/345959025

The water extractor is a part of the air conditioning pack. Fig. 14 shows the Airbus A320 water extractor, which is part of the air conditioning packs. The inlet of the water extractor is covered with black oily residue because the temperature is even lower at this point.



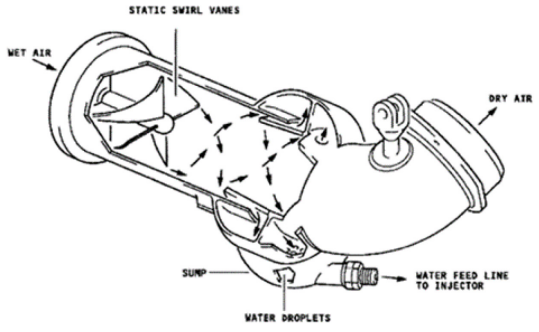
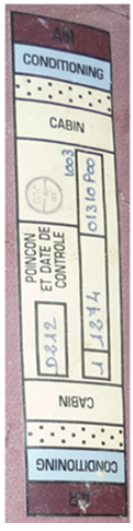


Fig. 14 - Engine oil residue accumulates in the water extractor. The schematic on the right is from [17]

3.3 Engine Oil Colors Cabin Air Ducts





The air conditioning air distribution ducts in the cabin are black inside from contaminated bleed air. Fig. 15 shows the Airbus A320 air conditioning air distribution duct in the cabin. The inside is black from contaminated bleed air.

Fig. 15 - Airbus A320 air conditioning air distribution duct in the cabin

Fig. 16 shows on the left side an unused duct supplied new. The right side of Fig. 16 shows the same duct that had been installed downstream of the environmental control system air conditioning packs on a BAe 146 passenger aircraft after 26061 flight hours.



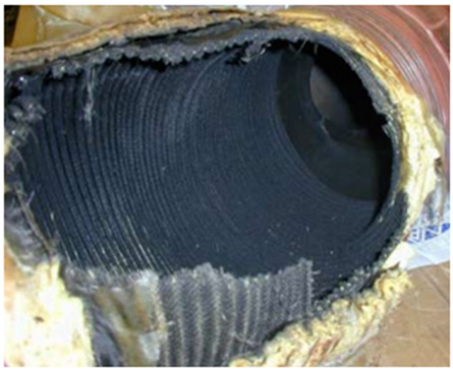


Fig. 16 - Left: Unused cabin air duct. Right: Used cabin air duct on a BAe 146 passenger aircraft [18]

Air ducts are even clean inside at the end of the aircraft's life, in areas where they are used such that no bleed air flows through them. Such an example is shown in Fig. 17. The inside of the air extract duct (located near the extract fan) is clean at the end of life of an Airbus A320, because the duct is normally not fed with bleed air. This disproves the argument that all ducts are black due to normal use over the course of decades in service.



Fig. 17 - Clean air duct at end of life of an Airbus A320

Flow limiters have been found in ducts of the air conditioning system clogged from engine oil. Fig. 18 shows flow limiters clogged from pyrolyzed engine oil in ducts of the air conditioning system of Boeing 757 aircraft with Rolls-Royce RB211-535E4 engines operated by Icelandair [19] compared to a clean flow limiter (top, left).



Fig. 18 - Top left: Clean flow limiter in an air conditioning duct on an Airbus A320 (here in a dead-end duct section installed for unknown reason) compared to flow limiters clogged from pyrolyzed engine oil in ducts of the air conditioning system of Boeing 757 aircraft [19]

Fig. 19 shows the riser ducts and lower cabin air outlet on an Airbus A320 aircraft. The red line in Fig. 19 close to the cabin floor indicates where the duct was separated and opened. Looking down to the cabin floor shows a duct feeding the riser ducts. It is black inside from

engine oil residue. Fig. 20 shows a view into the riser duct at that end, where it was separated at the cabin floor. It is also black inside.

It has been argued that on old aircraft, cabin air ducts could be black inside due to cigarette smoke. This however is not likely for three reasons:

1. The bans on inflight smoking have been introduced gradually around the world beginning in the 1980s. An aircraft that is flying or is parted out today (like the one from which most of the picture are taken) will most probably have not seen any onboard smoking.
2. Air can only get into the cabin air ducts after it has be recirculated through the HEPA filters, which would filter out smoke particles.
3. Ducts are contaminated starting from the bleed air ducts connected with the engine. Cigarette smoke would not explain contamination of these ducts.





Fig. 19 - Left: Riser ducts and lower cabin air outlet on an Airbus A320 aircraft. The red line close to the cabin floor shows, where the riser ducts are attached to their supply duct. See: Video: https://youtu.be/jHGu83gC6V4. Top: View into the supply duct leading up into the riser duct on an Airbus A320. The inside is covered by a black residue





Fig. 20 - View into the riser duct where it was separated at the cabin floor. It is covered inside by black residue

3.4 Engine Oil on Overhead Bins

Cleaning on top of the overhead bins of an Airbus A320 brings to light dirt that is clearly more than dust. The black residue similar to that known from the ducts settles also on the bin surface, as shown on the left side of Fig. 21. The right side of Fig. 21 shows an Airbus A320 cabin cross section with the upper cabin air outlet releasing potentially contaminated air on top of the overhead bins.

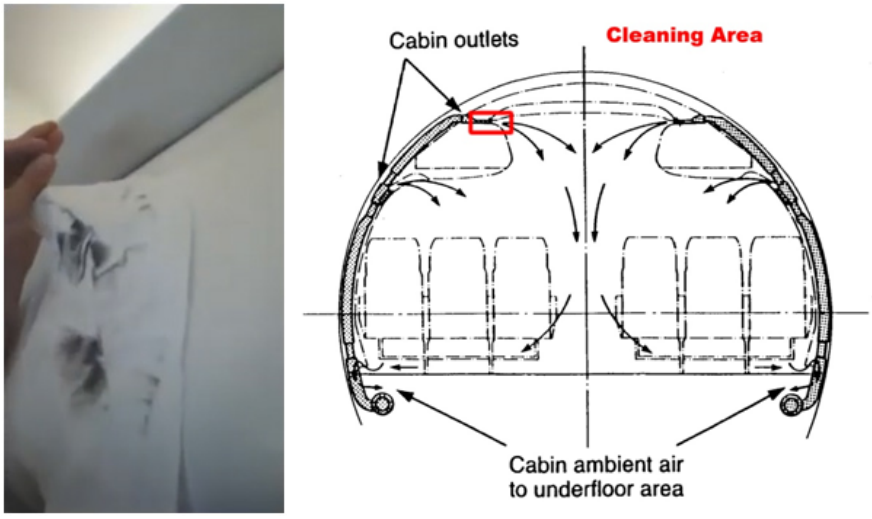


Fig. 21 - Left: Cleaning on top of the overhead bins of an Airbus A320 brings to light dirt that is clearly more than dust. The black residue known from the ducts settles also on the bin surface. Picture source: Video: https://youtu.be/uQfA_DiMBS8. Right: Airbus A320 cabin cross section with the upper cabin air outlet releasing potentially contaminated air on top of the overhead bins (based on [17])

4. DISTRIBUTION OF HYDRAULIC AND DEICING FLUID

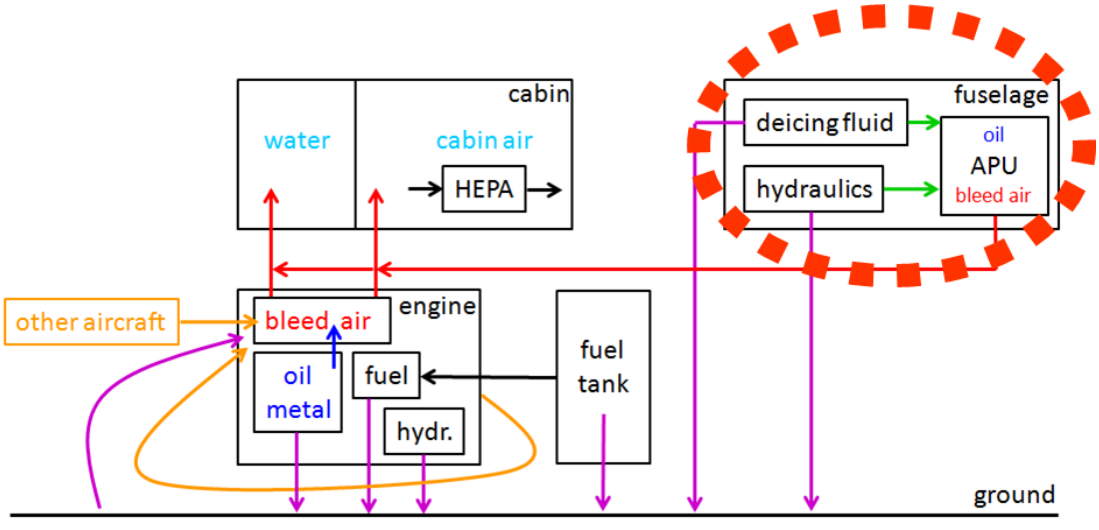


Fig. 22 - The route of hydraulic and deicing fluid into the cabin

4.1 APU Air Intake

Deicing fluid and hydraulic fluid can find their way into the air conditioning system via the APU air intake. The location of the APU air intake is shown in Fig. 23.

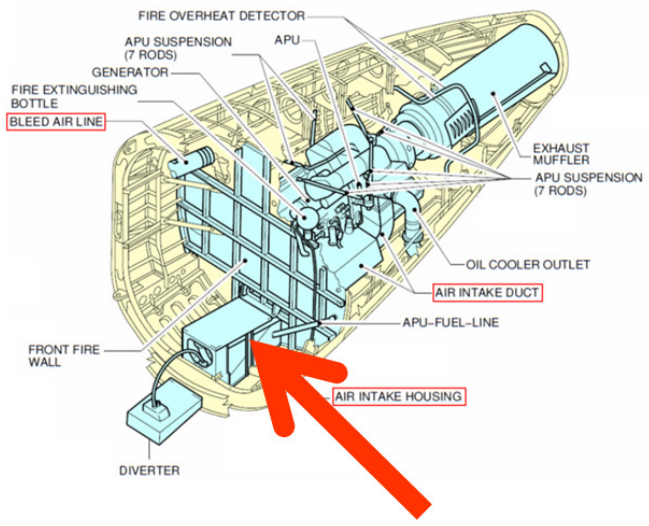


Fig. 23 - APU air intake [20]

The left side of the Fig. 24 shows the air intake of the A320 APU. Fence and deflector around the APU air intake are clearly visible. These measures cannot fully prevent contaminants from entering the APU. On the right side of Fig. 24 traces of contamination are clearly visible on the lower part of the fuselage. Carried by the air flow in flight, the contaminants reach the APU inlet.

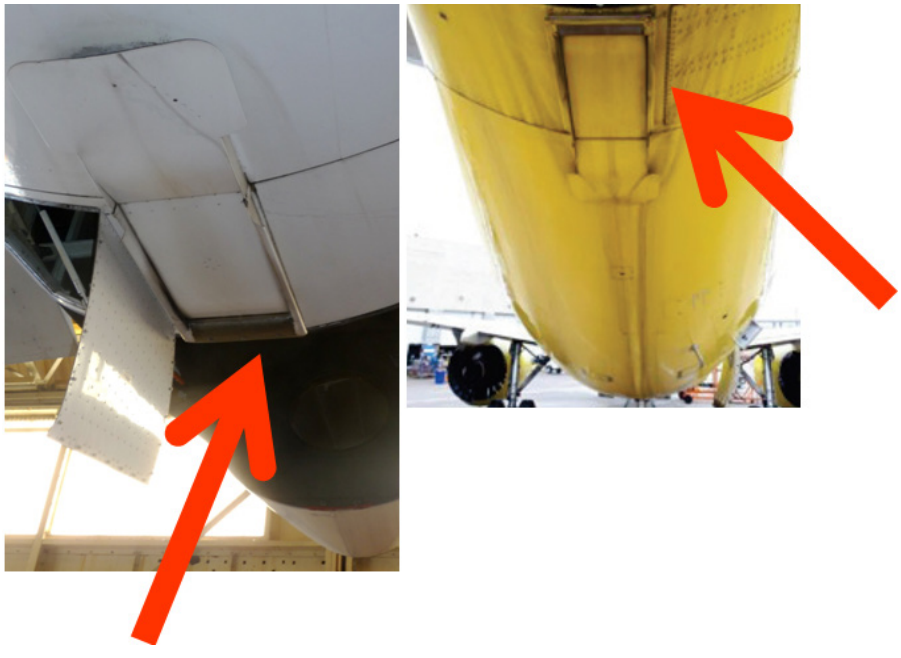


Fig. 24 - Air intake of the A320 APU. Source of picture on the right: [21]

4.2 No "Zero Leakage" of Hydraulic Systems

Hydraulic systems are never leak free. A hydraulic seal drain system tries to collect hydraulic fluid leaving the system with partial success. It is impossible to catch all leaking hydraulic fluid. If the containers of the seal drain system are not emptied, they spill over. Either way, the fluid finds its way to the APU inlet. Fig. 25 and 26 show the forward and aft collector tank of the A320 hydraulic seal drain system.



Fig. 25 - Forward (left) and aft (right) collector tank of the A320 seal drain system [22] and [23]



Fig. 26 - Aft collector tank of the A320 seal drain system, ATA 29-17. Forward and aft collector tanks collect hydraulic fluid from leaking equipment in the landing gear compartment, but spillover into the landing gear compartment when full. The photo tries to explain, what is meant with "the hydraulics industry must clean up its messy image". In this old Airbus A320, all surfaces in the landing gear bay are covered with a layer of hydraulic fluid. Dirt accumulates on the sticky surface. Logically, the hydraulic fluid is not confined to the inside of the hydraulic bay, but continues the lower side of the fuselage, if not cleaned constantly and finds its way to the APU inlet

4.3 Aircraft Deicing

In Fig. 27 shows how deicing fluid is applied and how it covers the surface of an aircraft. The purpose is to clean the aircraft from frost and snow and to protect it from further onset. Deicing fluid can leak from the tail into the APU inlet as shown in Fig. 28.



Fig. 27 - Leakage of deicing fluid [24]

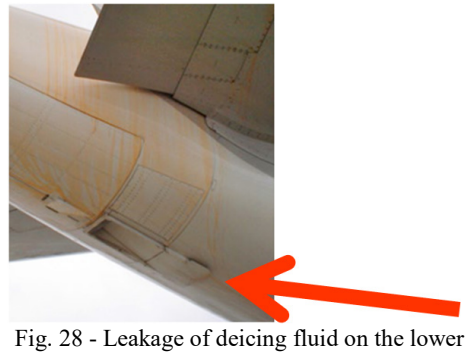


Fig. 28 - Leakage of deicing fluid on the lower side of the fuselage into the APU [25]

5. DISTRIBUTION OF FLUIDS VIA AIRPORT SURFACES

Fuel and oil also leak down onto the airport surfaces. Fig. 29 shows the route of fluids down to the ground and back into the engine.

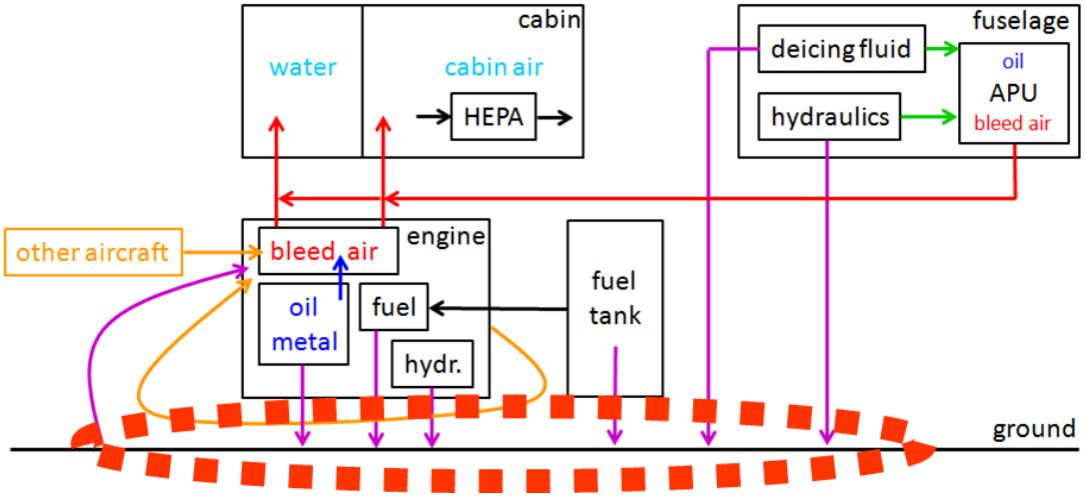


Fig. 29 - The route of fluids down to the ground and back into the engine

5.1 Leak Limits of Aircraft Equipment

There are leak limits of aircraft equipment as shown in Fig. 30. These leak limits show that it is normal for fluids to drip in smaller quantities on the ground. However, an airport sees many airplanes dripping and it all adds up over weeks, months and years.

INSPECT/CHECK	MAXIMUM SERVICEABLE LIMITS
Oil	
The starter pad	7 drops/min
The AGB rear hydraulic pump pad	7 drops/min
The AGB fuel pump pad	7 drops/min
The lube unit pad	No leaks allowed
The main oil/fuel heat exchanger	7 drops/min
The AGB/IDG pad	7 drops/min
The forward sump	20 drops/min
The Aft sump (flooding drain)	Any amount, less than 20 drops/min after engine shutdown.
The Aft sump area	No leak allowed
INSPECT/CHECK	**MAXIMUM SERVICEABLE LIMITS**
Fuel	
The fuel manifold shroud	No leaks allowed
Fuel pump at the AGB drive pad	60 drops/min (up to 90 drops/min allowed for 25 cycles)

Fig. 30 - A320 leak limits for the CFM56-5B engine in drops per minute. Drops add up over time [26].
AGB: Accessory Gearbox. IDG: Integrated Drive Generator

5.2 Intake of Fluids by the Engine

Fluids that leak on the ground can be ingested by the engine from the ground and can enter the air conditioning system from there. Fig. 31 shows the simulation of two intake vortices, one of them as ground vortex. The rotation of the vortex is visible. Fig. 32 shows the same situation in a photograph.

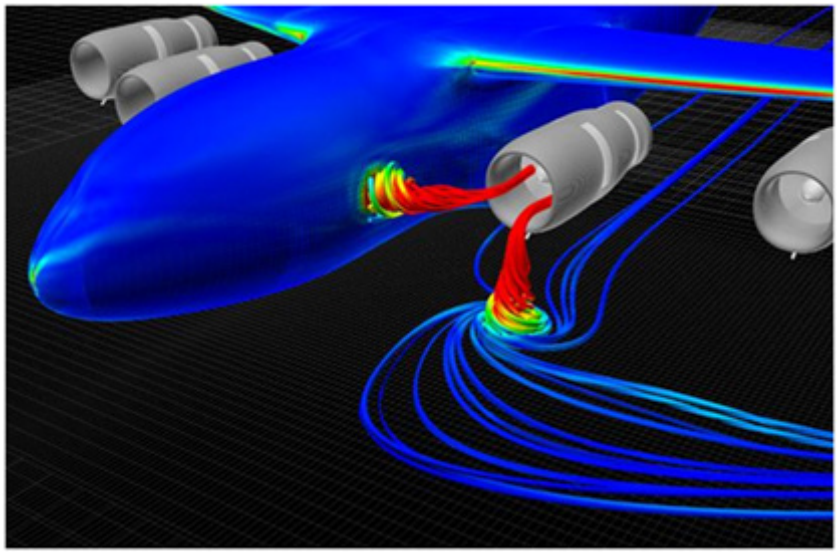


Fig. 31 - Simulation of two intake vortices, one of them as a ground vortex. The rotation of the vortex is visible. Picture source: https://perma.cc/VH99-87XS



Fig. 32 - The ground vortex can also form between the ground and an engine on a high wing [27]

6. MORE CONTAMINATION

The location of the recirculation fan of an Airbus A320 is shown in Fig. 33. The face of the recirculation fan of an Airbus A320 is covered by an oily black soft substance that can be scraped off with a screwdriver (Fig. 34).

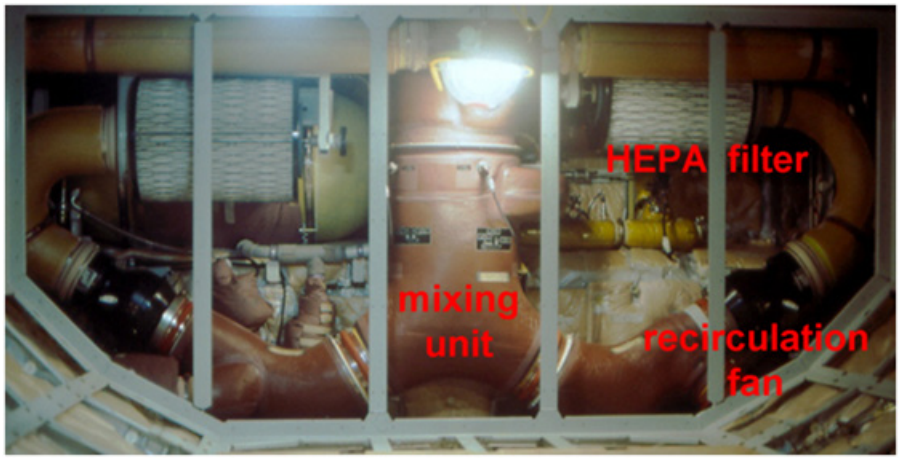


Fig. 33 - The main component of the Airbus A320 recirculation system. View from the forward cargo compartment looking aft. The wall panels in the cargo compartment are not installed. The support frames for the wall panels are visible. Two HEPA filters and two recirculation fans are installed symmetrically



Fig. 34 - The recirculation fan of an Airbus A320 is covered by an oily black soft substance that can be scraped off with a screw driver. Picture source: Video: https://youtu.be/jHGu83gC6V4. A disassembled recirculation fan is shown on the right.

Fig. 35 shows the ambient air inlet in the cargo compartment of the Airbus A320 for cargo compartment heating and ventilation. The inlet is full of moist dust.



Fig. 35 - The ambient air inlet in the cargo compartment of the Airbus A320 for cargo compartment heating and ventilation. The inlet is full of moist dust

7. CONCLUSIONS

Pyrolized engine oil, hydraulic and deicing fluid as well as nanoparticles from engine debris are problematic for human health. These substances can find their way via various routes into cabin air and potable water on board of aircraft. Most discussed is the path of engine oil and its additives via bleed air into the cabin air. But there are other substances, paths and sources of leakage. The engineering assumption is that engine oil and hydraulic fluids operate in closed systems. A detailed look shows however that this assumption is wrong. Nothing is perfect, systems wear out or fail. No seal is fully tight. Fighting entropy does not work. Entropy is the law of nature that states that disorder always increases, as shown in Fig. 36. This is the reason, why it is fundamentally impossible to confine engine oil and hydraulic fluids to their (predominantly) closed aircraft systems. This is why engine oil with metal nanoparticles hydraulic fluids, and deicing fluids eventually go everywhere and finally into the human body.

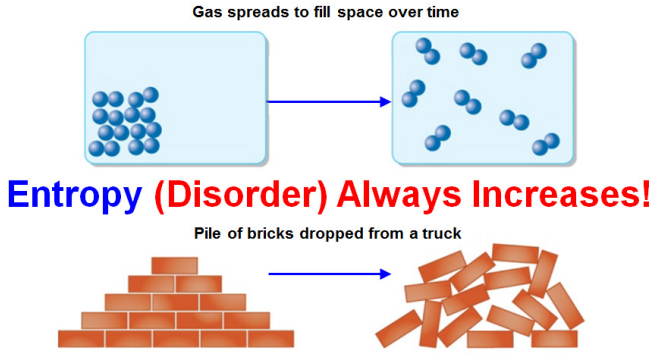


Fig. 36 - Disorder always increases (based on https://perma.cc/A6KL-XS9R)

ACKNOWLEDGEMENTS

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Aircraft Cabin Air and Engine Oil – Routes of Contamination

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Abstract

Purpose: This conference paper discusses potential contamination of the air in passenger aircraft cabins. It gives an overview of cabin air contamination basics. It further names possible contamination sources and possible routes of contamination.
Methodology: Evidence follows from a review of material found on the Internet and from the documentation of a visit to an aircraft recycling site. Parts were retrieved at the site and investigated later with more time.
Findings: Jet engine seals leak oil in small quantities. Metallic nanoparticles are found in the oil and have been detected in human fatty tissue of aviation workers. It has been observed that the potable water on board can also be contaminated. Oil traces have been found in bleed ducts, air conditioning components, and in air conditioning ducts. Deicing fluid and hydraulic fluid can find their way into the air conditioning system via the APU air intake. Fuel and oil also leak down onto the airport surfaces. These fluids can be ingested by the engine from the ground and can enter the air conditioning system from there. Entropy is the law of nature that states that disorder always increases. This is the reason, why it is impossible to confine engine oil and hydraulic fluids to their (predominantly) closed aircraft systems. This is why engine oil with metal nanoparticles hydraulic fluids, and deicing fluids eventually can go everywhere and finally into the human body.
Research Limitations: No measurements have been made.
Practical Implications: Awareness and prevention of contaminated cabin air can protect passengers and crew.
Social Implications: The exposure of contaminated cabin air provides a basis for a general discussion and shows that people should be alerted and need to act. New technologies need to be implemented such as a bleed free architecture.
Originality: This paper shows probably more images with parts upstream of the engine compressor contaminated by leaking engine oil than any previous publication.

Keywords

aircraft, passenger, cabin, engine, bearing, lubrication, oil, seal, compressor, hydraulic, deicing, fluid, bleed air, contamination, ventilation, APU, ingestion, air conditioning, entropy, fume event, CACE

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1 Introduction

Cabin air ventilation in passenger aircraft is done with outside air. At cruise altitude, ambient pressure is below cabin pressure. Hence, the outside air needs to be compressed before it is delivered into the cabin. The most economic system principle simply uses the air that is compressed in the engine compressor and taps some of it off as "bleed air". This principle is explained in Scholz 2014a (German) and Scholz 2018 (English). In the context of contaminated cabin air the background can be found in Scholz 2017a, Scholz 2017b, and Scholz 2019. **Figure 1** shows the contaminants and their routes into the cabin. The individual routes are explained below.

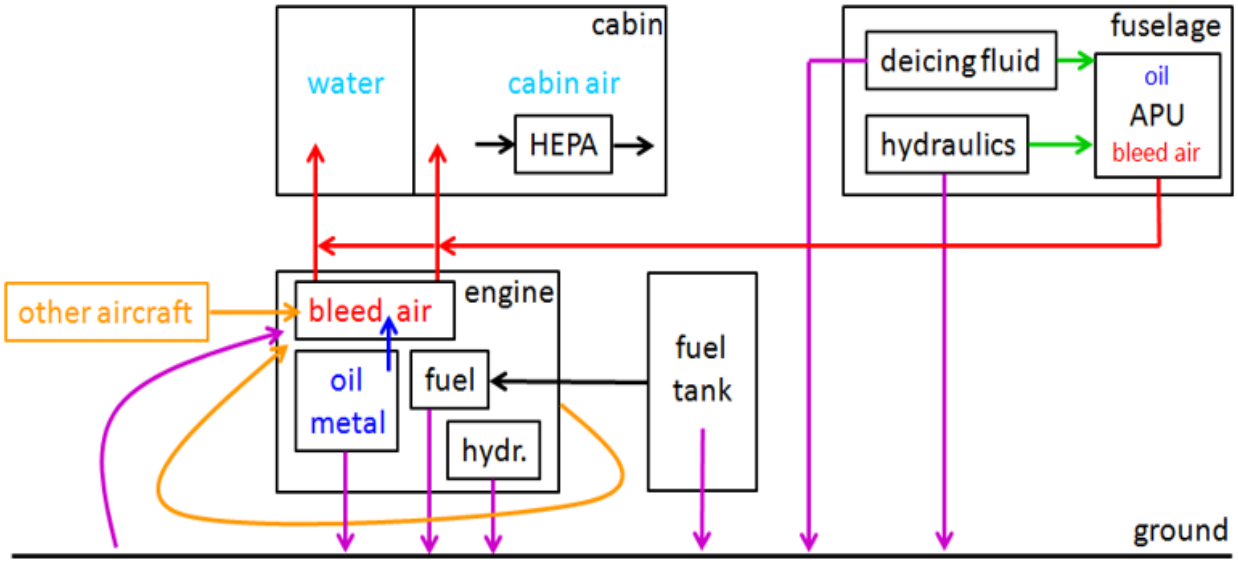


Figure 1 Contaminants and their routes into the cabin.

Route in blue: Seals at the engine bearings leak by design (Chapter 2). The leaking oil includes metal nano particles (Chapter 3). The oil with metals finds its way into the engine compressor. The same holds for the APU.

Routes in green: Deicing fluid sprayed on the tail of the aircraft flows down along the surface of the aft fuselage and surrounds the air intake of the APU at the bottom of the fuselage. Hydraulic fluid leaks from the main landing gear bay and is directed along the outside of the fuselage, to the APU air intake. In this way deicing fluid and hydraulic fluid can enter the APU via its air intake (Chapter 4).

Routes in red: Oil and metal from the engines find their way via bleed air into the cabin (Chapter 3) and into the potable water (Chapter 3.1). Oil leaks also from the APU into the APU bleed air and into the cabin. In addition, deicing fluids and hydraulic fluids make their way via the APU bleed air into the cabin.

Routes in purple: Deicing fluids, hydraulic fluids, oil, and fuel (from the fuel tank or from the engine) drip on the ground. The engine ingest these liquids from the ground (Chapter 5). Once in the engine compressor, the liquids find their way via the bleed air into the cabin.

Routes in orange: Exhaust gases from other aircraft are ingested. In case of a strong tailwind on the ground or in case of reverse thrust at landing, the engine ingests its own exhaust. Contaminates find their way via the bleed air into the cabin.

HEPA filter: In the cabin, HEPA filter are part of the recirculation (Chapter 6). Standard HEPA filters cannot mitigate the problem of oil contamination.

2 Jet Engine Technology and Results

The engine shaft is supported by lubricated bearings. **Figure 2** shows the location of the bearings in a jet engine and the position, where the bleed air is tapped off for cabin ventilation.

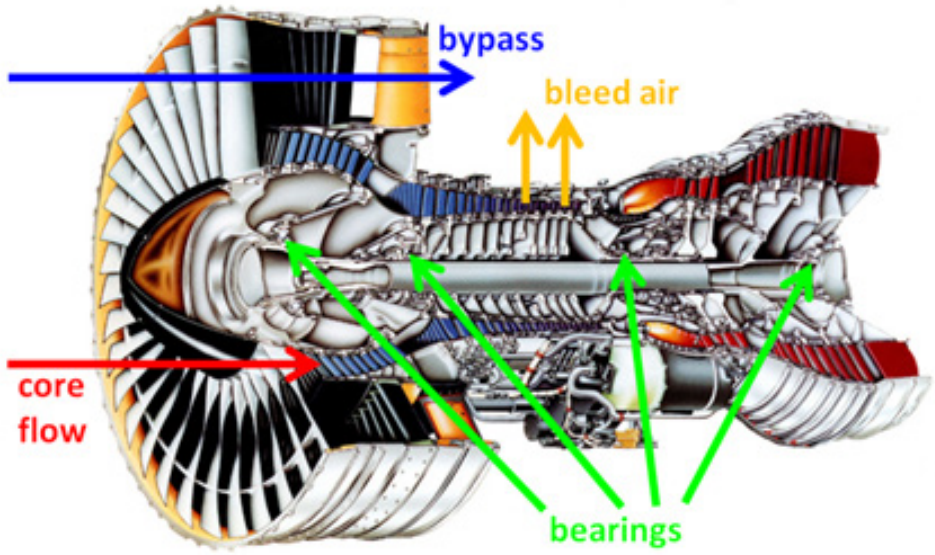


Figure 2 Engine bearings and bleed air (based on P&W 2014).

The bearings are sealed against the air in the compressor usually with labyrinth seals, shown in **Figure 3**. Unfortunately, the jet engine seals leak oil by design in small quantities. Even more so, the seals leak oil in certain flight phases, when they are worn out, or in failure cases.

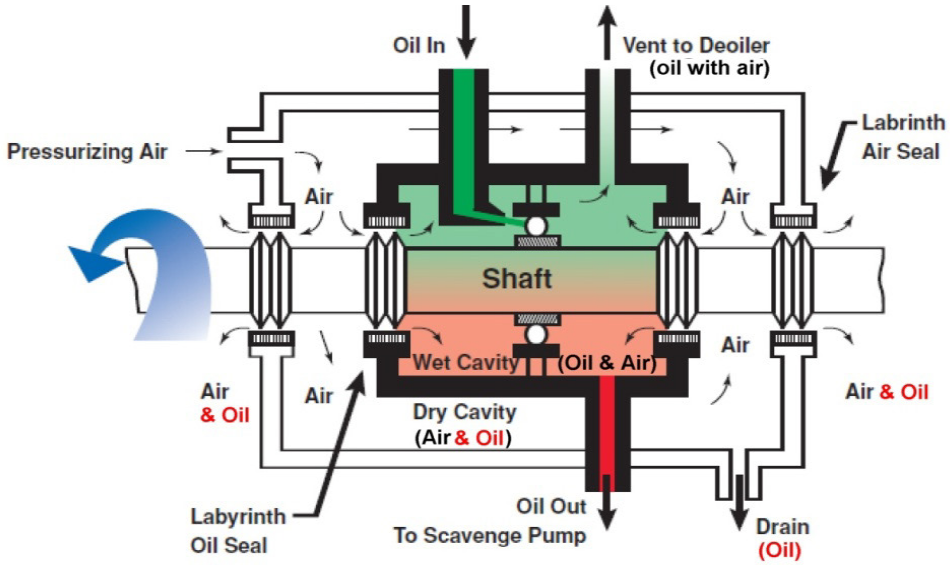


Figure 3 Lubrication and sealing of engine bearings (based on Exxon 2017).

Even in normal operation, the engine seals leak small quantities of oil. This follows from **Figure 3** and these observations:

1. The "drain" discharges oil.
2. The "dry cavity" contains oil.
3. Air and oil leak from bearings into the bleed air.

Accordingly, engines leak small amounts of oil by design. The oil leaking into the compressor contains toxic additives. Furthermore, the oil includes toxic metal nanoparticles – normal debris from the engine. These metal nanoparticles in the oil are finally proven in human fatty tissue of aviation employees as shown in **Figure 4**.

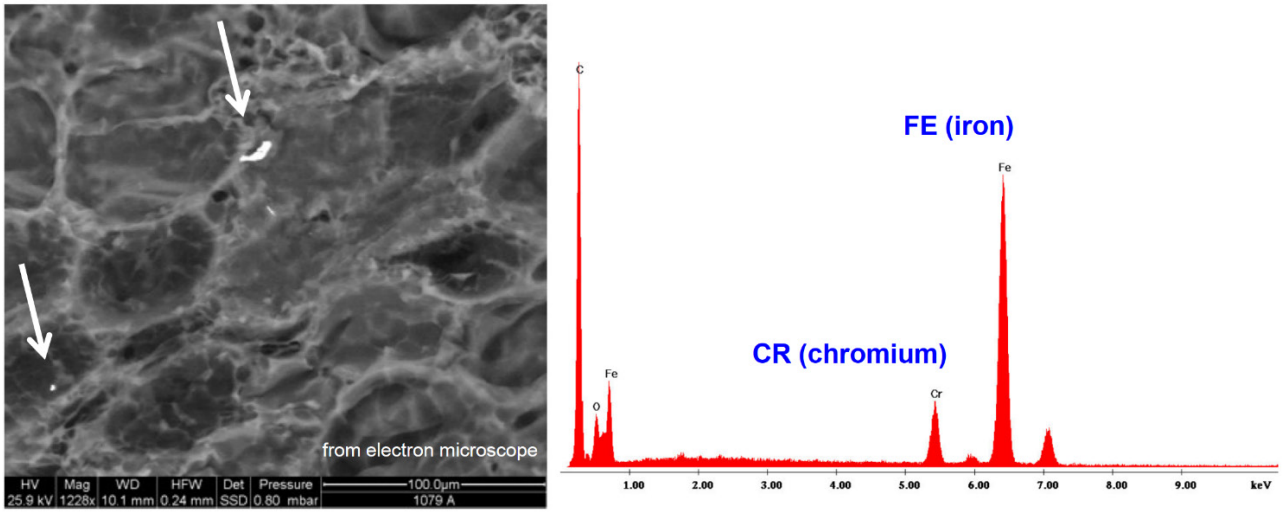


Figure 4 Analysis 8 of Table I. High-magnification image (1228x) and EDS (Energy-Dispersive X-ray spectroscopy) spectrum of 10-micron and 1-micron brighter-looking particles composed of Carbon, Iron, Chromium and Oxygen: a stainless-steel composition (Gatti 2019, report written for client).

3 Distribution of Engine Oil with Metal Nanoparticles

An alternative source for the compressed air is the Auxiliary Power Unit (APU). Like the aircraft's jet engine, it is a gas turbine, built much in the same way when it comes to bearings and seals. For this reason, also compressed air from the APU is potentially contaminated in much the same way. **Figure 5** shows the route of the engine oil into the cabin.

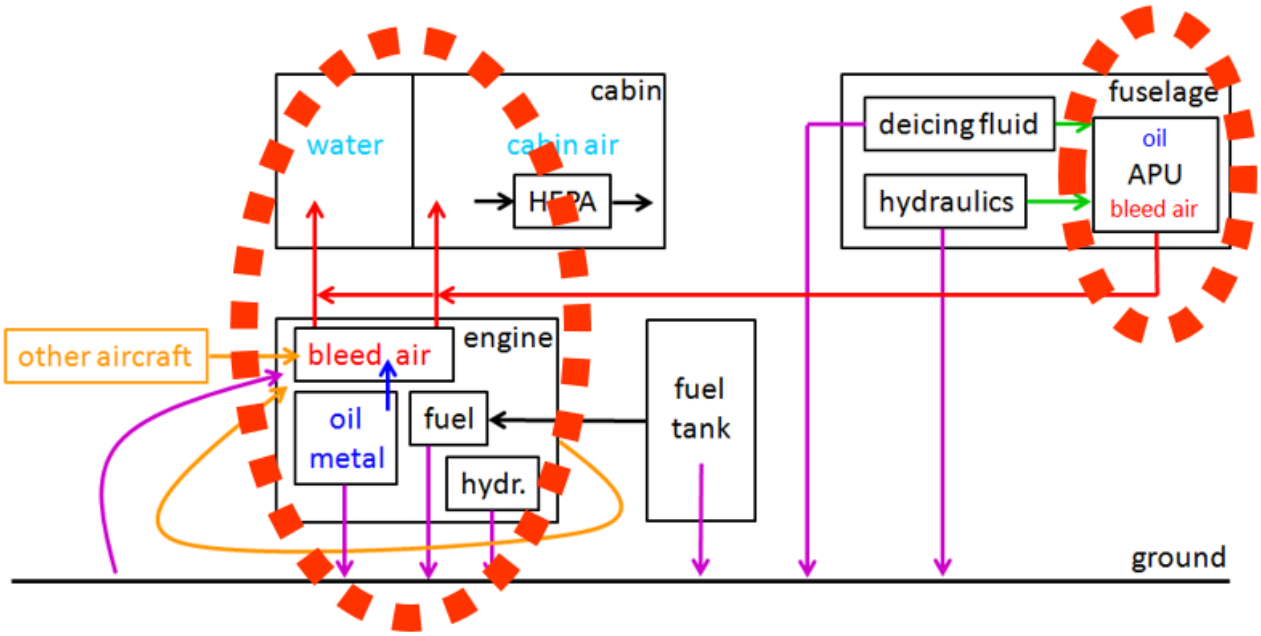


Figure 5 The route of engine oil into the cabin.

The **Figures 6 to 9** show the inside of a cabin in a Cabin Air Contamination Event (CACE) due to engine oil after a technical fault.



Figure 6 2010-09-17, US Airways US-432, Boeing 757-200. Maui-bound flight enroute overhead the Pacific diverted to San Francisco (1200 nm). More: AvHerald 2010. Picture source: Video: https://youtu.be/AZqeA32Em2s.



Figure 7 2018-12-10, Indigo flight 6E-237, Airbus A320neo, Jaipur to Kolkata, India. The smoke was traced down to the engines (PW1127). This and more: AvHerald 2018. Cause: Leakage of oil from the engine (Telegraph 2018). Picture source: Video: https://youtu.be/TO_FZ3L4yus.

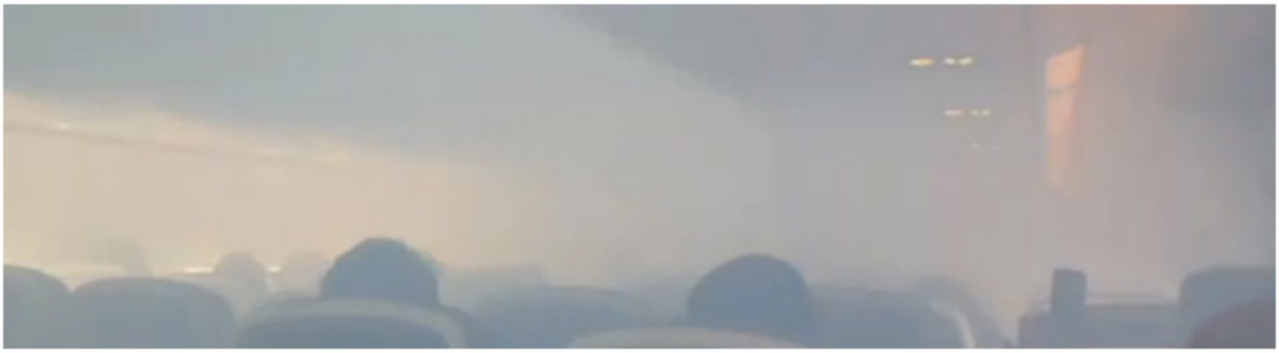


Figure 8 2019-08-22, Hawaiian Airlines HA47, A321neo. Emergency landing and evacuation after smoke on board. Cause: Seal failure in left engine. Picture source: Glen Westenskow. This picture and more: AvHerald 2019a. More also on https://purl.org/cabinair/HA47.



Figure 9 2019-08-05, British Airways BA-422, Airbus A321. On a flight from London Heathrow to Valencia, the aircraft was descending towards Valencia when smoke appeared in the cabin. It followed an emergency evacuation. The aircraft remained 9 days in Valencia and was subsequently ferried to London. After a total of 31 days the aircraft returned back to service (Ayan 2020). "It was found that no fire had occurred, but engine #2 (V2533, right hand) had lost all its oil. The engine was removed from the airframe and sent to the manufacturer for thorough inspection." This and more on: AvHerald 2019b. Picture source: Lucy Brown. Video: https://youtu.be/tFsN0h09gAI.

3.1 Engine Oil in the Potable Water

Compressed air from the engine is also used to pressurize the potable water tanks on some aircraft like the Airbus A320 (Scholz 2014b). It has been observed that the potable water on board can also be contaminated. Potable water contaminated by bleed air on an Airbus A320, is shown in **Figure 10**. It is the last water extracted from the tank before it is empty. This water is black, probably from engine oil residue.



Figure 10
Potable water contaminated by bleed air on an Airbus A320. This is the last water extracted from the tank before it is empty. This water is black, probably from engine oil residue. Picture source is a Video: https://youtu.be/dlPOeudTTCI. The video is explained: On the A320 the potable water tank is pressurized with bleed air. On the A320 also the hydraulic reservoirs are pressurized with bleed air. The bleed air presses on the free surface of the hydraulic fluid and gets as such in contact with it. The "mixture of hydraulic fluid vapor and bleed air" is connected via bleed lines with the potable water tanks. But flow into the potable water tanks is unlikely:

- In flight, the "mixture of hydraulic fluid vapor and bleed air" would need to flow upstream and opposite sense through two check valves (which by design will not happen in larger quantity) to get into the bleed line for water pressurization.
- On the ground (without bleed pressure), the hydraulic fluid vapor and bleed air mixture can flow downstream(!) but would still need to flow opposite sense through two check valves (which by design will not happen in larger quantity) to get into the bleed line for water pressurization.

3.2 Engine Oil Colors Bleed Air Ducts

When an engine is taken off the aircraft, two air ducts become visible: the duct for the fan air and the duct for the bleed air. Fan air and bleed air ducts at the interface between engine and wing carry outside compressed air. **Figure 11** shows a diagram from the Airbus A320. The red line indicates the cut when separating the engine from the wing. The fan air is fresh outside air that has at best touched the fan blades (or the outlet guide vanes) on its way through the engine bypass. On the other hand, the bleed air is fresh outside air that has gone through the core of the engine. If everything were right, there should not be a difference depending on where the outside air gets compressed. Unfortunately, there is a difference. Bleed air is potentially contaminated with engine oil. This can be seen in **Figure 12**. The fan air duct shows a normal metallic surface color, whereas the bleed air duct at the engine interface appears brown. The bleed air temperature at this point is about 300 °C ... 400 °C, the fan air is closer to ambient temperature. Metal on its own does not turn to a brown color when heated to 400 °C. The only explanation with respect to the difference in the color of the two ducts is that the bleed air is covered by a brown residue. Confirmation comes from touching the surface. If not deposited in the duct, the substance causing the residue makes otherwise its way into the cabin. We know from engineering (**Figure 3**) that jet engine seals leak oil by design. Therefore, the brown residue in the bleed air duct compared to the fan air duct is a confirmation that oil leakage takes place in the engine.

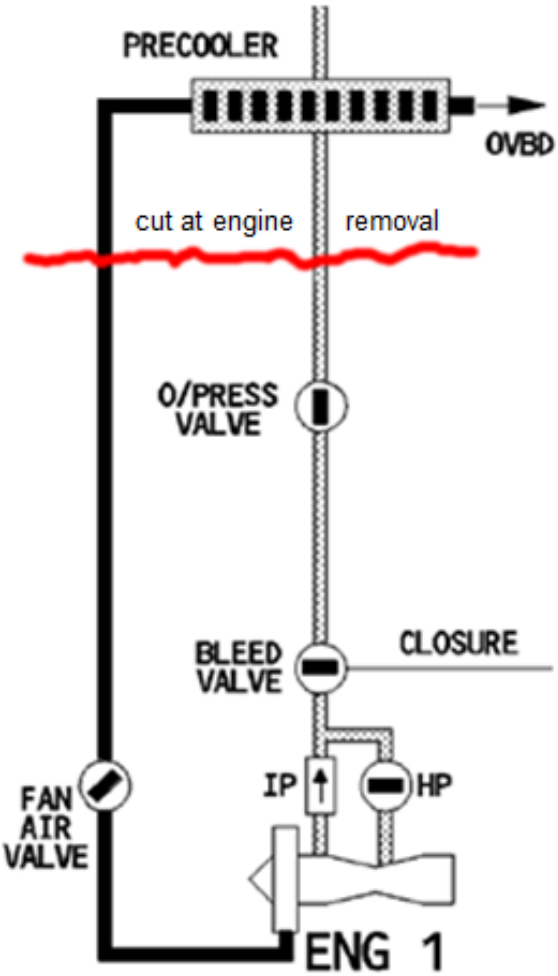


Figure 11 Fan air and bleed air taken off a jet engine. The red line indicates where the fan air duct and the bleed air duct are separated, when the engine is taken off. The diagram is a simplification based on a diagram explaining the pneumatic system (ATA 36) in the Airbus A320 FCOM.

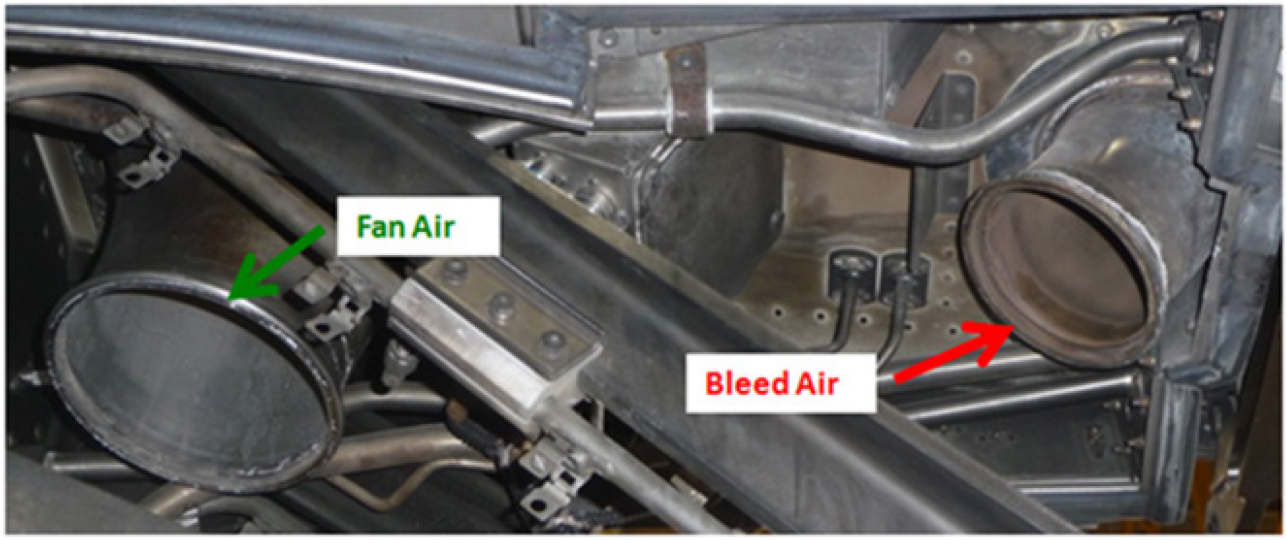


Figure 12 Bleed air duct with brown stain compared to a clean fain air duct on an Airbus A320.

Ducting further downstream shows a black dry cover. The reason for the change in color seems to result from the different air temperatures: 400 °C at engine outlet and 200 °C further downstream behind the precooler. **Figure 13** shows bleed air duct of a Boeing 737 with black oil residue inside.



Figure 13 Engine oil colors bleed air duct black. Picture source: Video: https://vimeo.com/groups/617439/videos/345959025.

The water extractor is a part of the air conditioning pack. **Figure 14** shows the Airbus A320 water extractor. The inlet of the water extractor is covered with black oily residue because the temperature is even lower at this point.

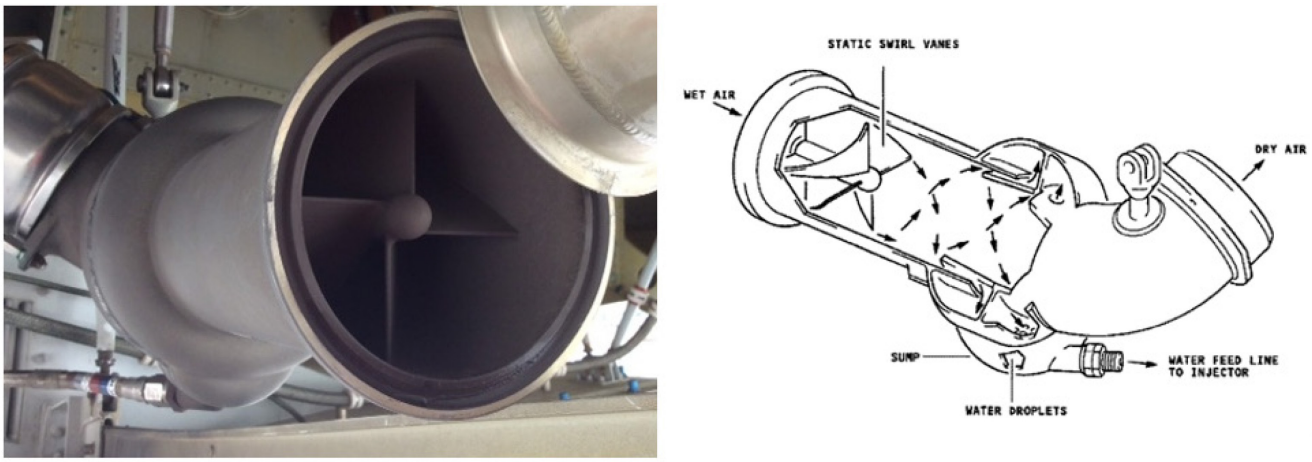


Figure 14 Engine oil residue accumulates in water extractor. The schematic on the right is from Airbus 1999.

3.3 Engine Oil Colors Cabin Air Ducts

The air conditioning air distribution ducts in the cabin are black inside from contaminated bleed air. **Figure 15** shows the Airbus A320 air conditioning air distribution duct in the cabin. The inside is black from contaminated bleed air.

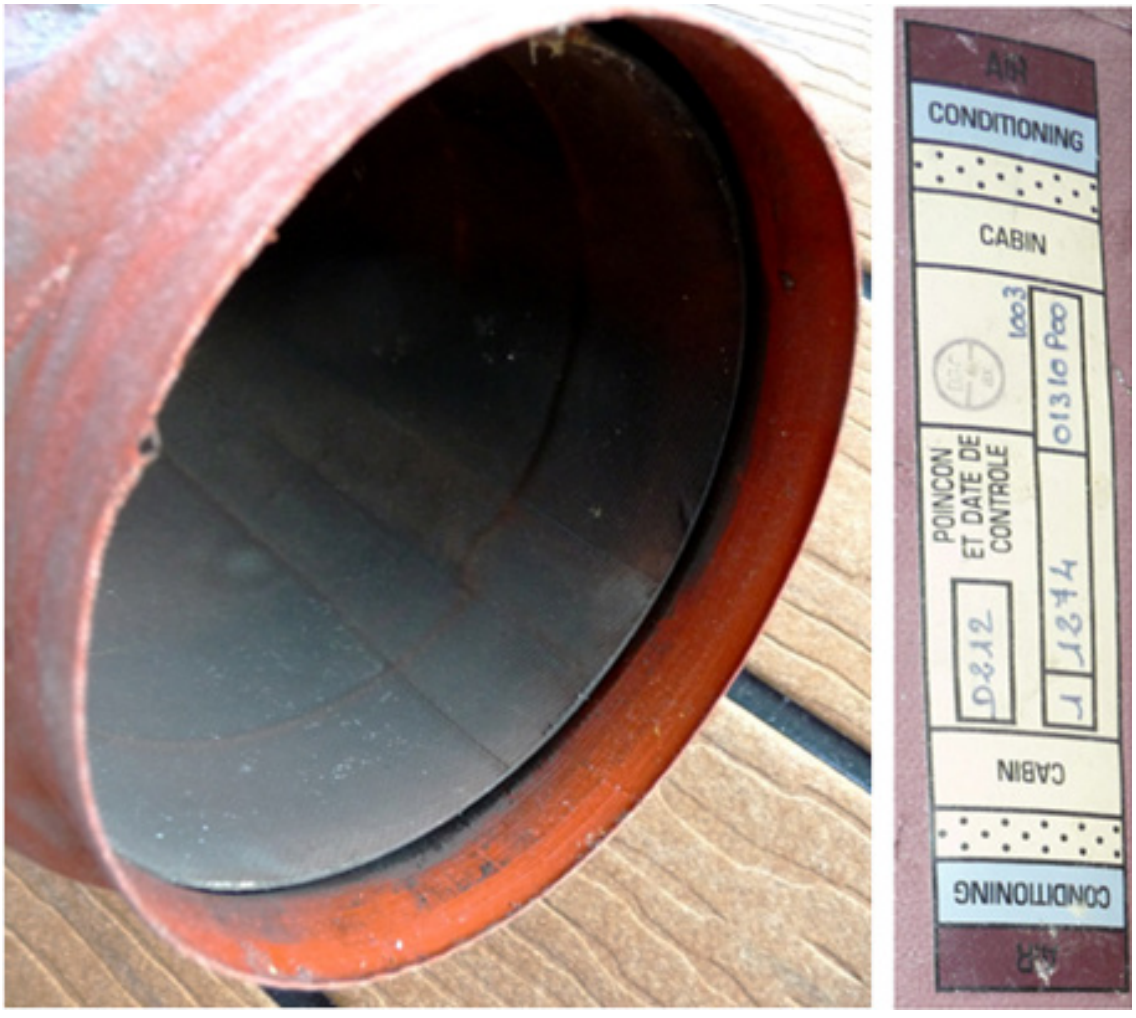


Figure 15 Airbus A320 air conditioning air distribution duct in the cabin.

Figure 16 shows on the left side an unused duct supplied new. The right side of Figure 16 shows the same duct that had been installed downstream of the environmental control system air conditioning packs on a BAe 146 passenger aircraft after 26061 flight hours.

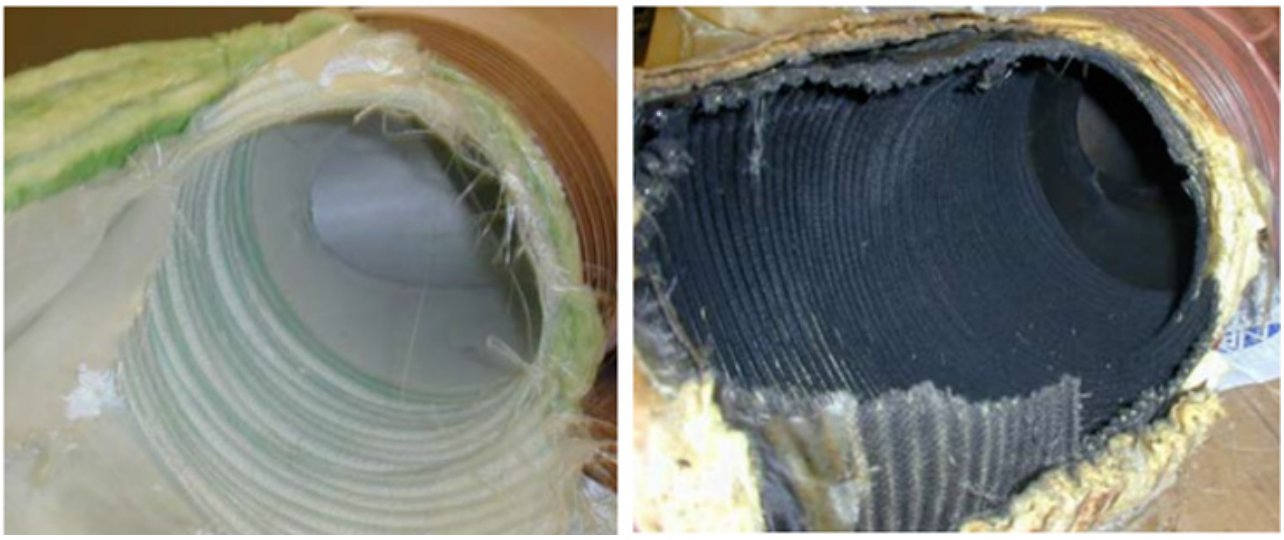


Figure 16 Left: Unused cabin air duct. Right: Used cabin air duct on a BAe 146 passenger aircraft (CAA 2004).

Air ducts are even clean inside at the end of the aircraft's life, in areas where they are used such that no bleed air flows through them. Such an example is shown in **Figure 17**. The inside of the air extract duct (located near the extract fan) is clean at the end of life of an Airbus A320, because the duct is normally not fed with bleed air. This disproves the argument that all ducts are black due to normal use over the course of decades in service.



Figure 17 Clean air duct at end of life of an Airbus A320.

Flow limiter in air conditioning ducts have been found in ducts of the air conditioning system that are clogged from engine oil. **Figure 18** shows flow limiters clogged from pyrolyzed engine oil in ducts of the air conditioning system of Boeing 757 aircraft with Rolls-Royce RB211-535E4 engines operated by Icelandair (Hansen 2019) compared to a clean flow limiter (top, left).



Figure 18 Top left: Clean flow limiter in an air conditioning duct on an Airbus A320 (here in a dead-end duct section) compared to flow limiters clogged from pyrolyzed engine oil in ducts of the air conditioning system of Boeing 757 aircraft (Hansen 2019).

Figure 19 shows the riser ducts and lower cabin air outlet on an Airbus A320 aircraft. The red line in Figure 19 close to the cabin floor indicates where the duct was separated and opened. Looking down to the cabin floor shows a duct feeding the riser ducts. It is black inside from engine oil residue. **Figure 20** shows a view into the riser duct at that end, where it was separated at the cabin floor. It is also black inside.

It has been argued that on old aircraft, cabin air ducts could be black inside due to cigarette smoke. This however is not likely for three reasons:

1. The bans on inflight smoking have been introduced gradually around the world beginning in the 1980s. An aircraft that flying or is parted out today (like the one from which most of the picture are taken) will most probably have not seen any onboard smoking.
2. Air can only get into the cabin air ducts after it has be recirculated through the HEPA filters, which would filter out smoke particles.
3. Ducts are contaminated starting from the bleed air ducts connected with the engine. Cigarette smoke would not explain contamination of these ducts.





Figure 19 Left: Riser ducts and lower cabin air outlet on an Airbus A320 aircraft. The red line close to the cabin floor shows, where the riser ducts are attached to their supply duct. See: Video: https://bit.ly/2YXcL3a (English subtitles available).

Top: View into the supply duct leading up into the riser duct on an Airbus A320. The inside is covered by a black residue.





Figure 20 View into the riser duct where it was separated at the cabin floor. It is covered inside by black residue.

3.4 Engine Oil on Overhead Bins

Cleaning on top of the overhead bins of an Airbus A320 brings to light dirt that is clearly more than dust. The black residue similar to that known from the ducts settles also on the bin surface, as shown on the left side of **Figure 21**. The right side of **Figure 21** shows an Airbus A320 cabin cross section with the upper cabin air outlet releasing potentially contaminated air on top of the overhead bins.

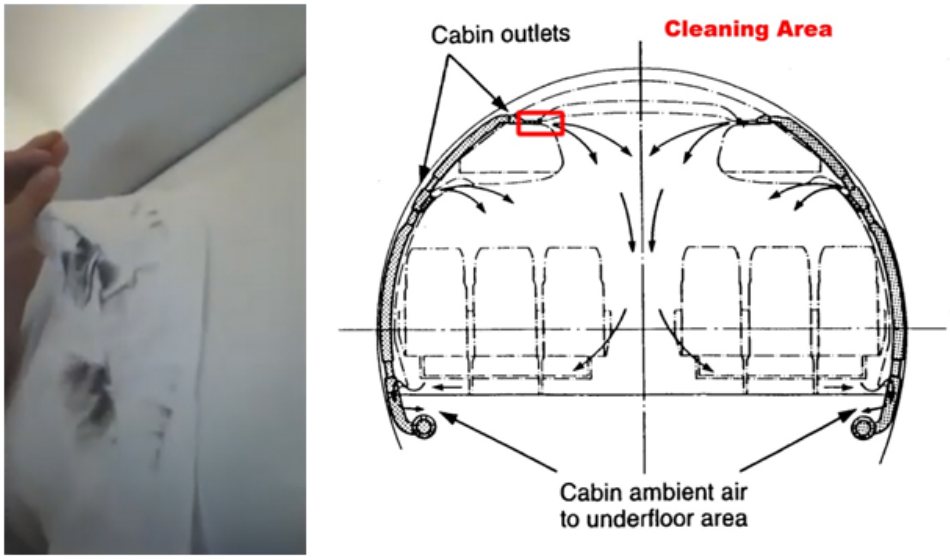


Figure 21 Left: Cleaning on top of the overhead bins of an Airbus A320 brings to light dirt that is clearly more than dust. The black residue known from the ducts settles also on the bin surface. Picture source: Video: https://youtu.be/uQfA_DiMBS8. Right: Airbus A320 cabin cross section with the upper cabin air outlet releasing potentially contaminated air on top of the overhead bins (based on Airbus 1999).

4 Distribution of Hydraulic and Deicing Fluid

Figure 22 shows the route of hydraulic and deicing fluid into the cabin.

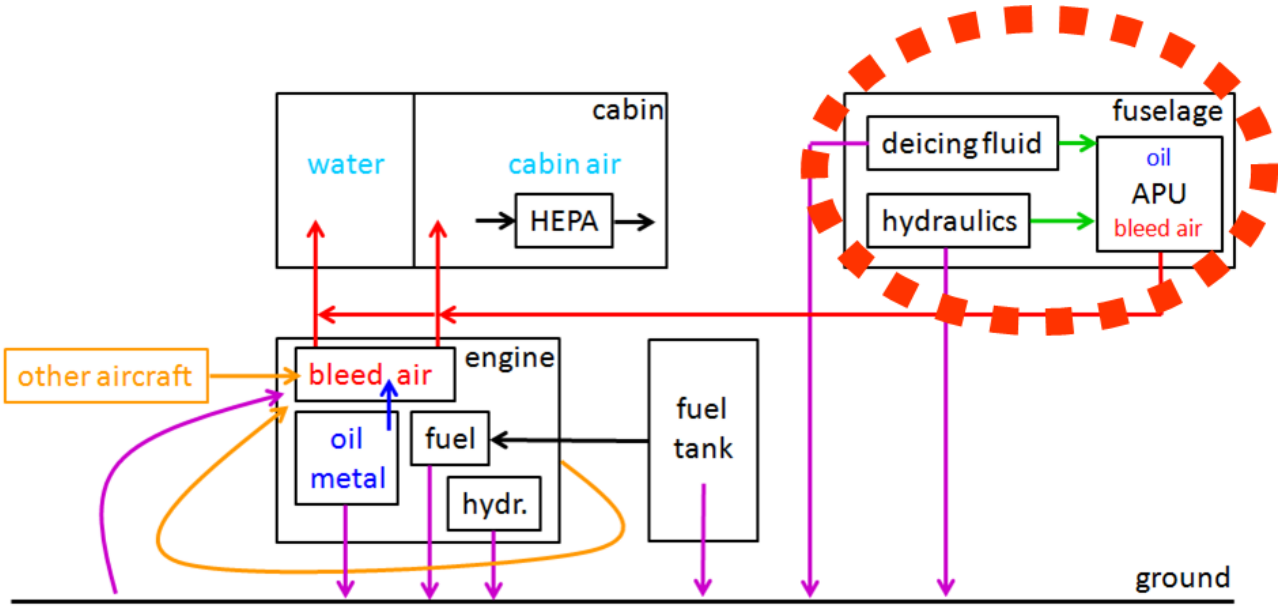


Figure 22 The route of hydraulic and deicing fluid into the cabin.

4.1 APU Air Intake

Deicing fluid and hydraulic fluid can find their way into the air conditioning system via the APU air intake. The location of the APU air intake is shown in **Figure 23**.

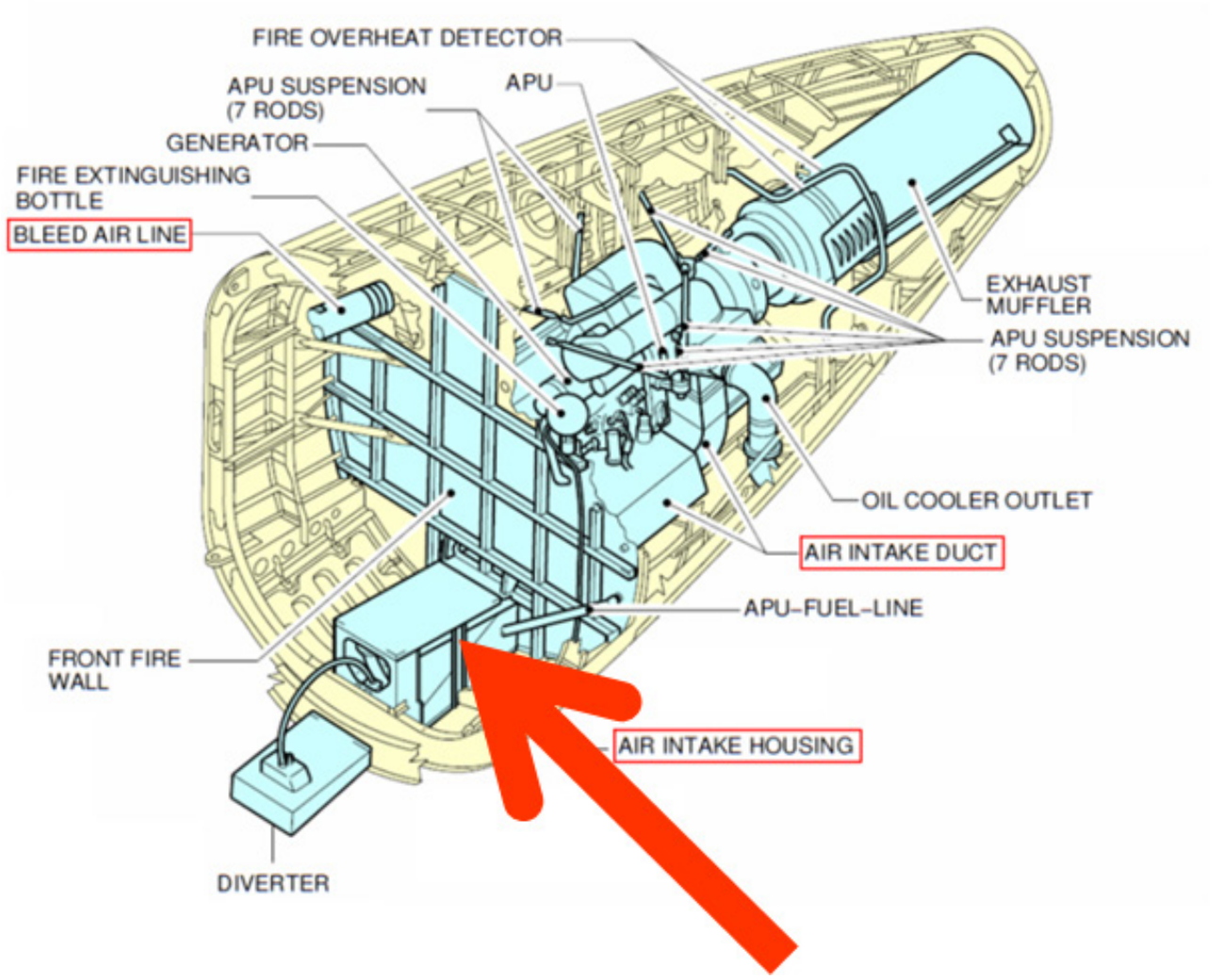


Figure 23 APU air intake (Airbus 2020).

The left side of the **Figure 24** shows the air intake of the A320 APU. Fence and deflector around the APU air intake are clearly visible. These measures cannot fully prevent contaminants from entering the APU. On the right side of Figure 24 traces of contamination are clearly visible on the lower part of the fuselage. Carried by the air flow in flight, the contaminants reach the APU inlet.



Figure 24 Air intake of the A320 APU. Source of picture on the right: Airbus 2019.

4.2 No "Zero Leakage" of Hydraulic Systems

Hydraulic systems are never leak free. A hydraulic seal drain system tries to collect hydraulic fluid leaving the system with partial success. It is impossible to catch all leaking hydraulic fluid. If the containers of the seal drain system are not emptied, they spill over. **Figure 25 and 26** show the forward and aft collector tank of the A320 hydraulic seal drain system.

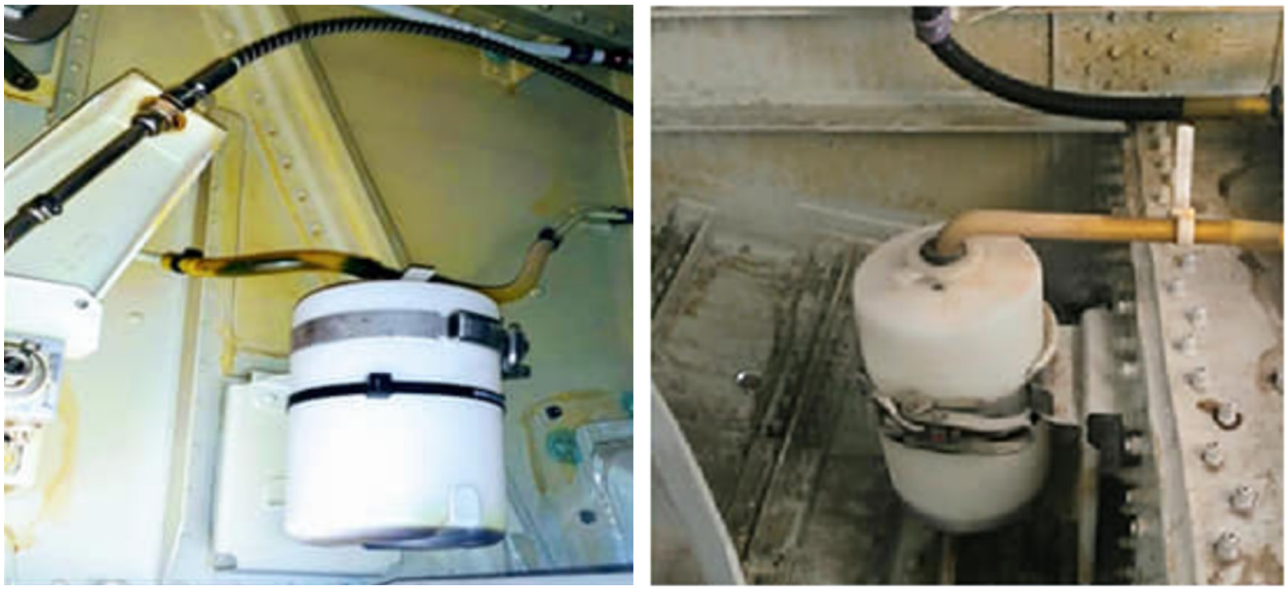


Figure 25 Forward (left) and aft (right) collector tank of the A320 seal drain system (Mekanikong 2019a and 2019b).



Figure 26
Aft collector tank of the A320 seal drain system, ATA 29-17 (Mekanikong 2019b). Forward and aft collector tanks collect hydraulic fluid from leaking equipment in the landing gear compartment, but spillover into the landing gear compartment when full. The photo tries to explain, what is meant with "the hydraulics industry must clean up its messy image". In this old Airbus A320, all surfaces in the landing gear bay are covered with a layer of hydraulic fluid. Dirt accumulates on the sticky surface. Logically, the hydraulic fluid is not confined to the inside of the hydraulic bay, but continues the lower side of the fuselage, if not cleaned constantly.

4.3 Aircraft Deicing

In **Figure 27** shows how deicing fluid is applied and how it covers the surface of an aircraft. The purpose is to clean the aircraft from frost and snow and to protect it from further onset. Deicing fluid can leak from the tail into the APU inlet as shown in **Figure 28**.



Figure 27 Leakage of deicing fluid (Petchenik 2015).

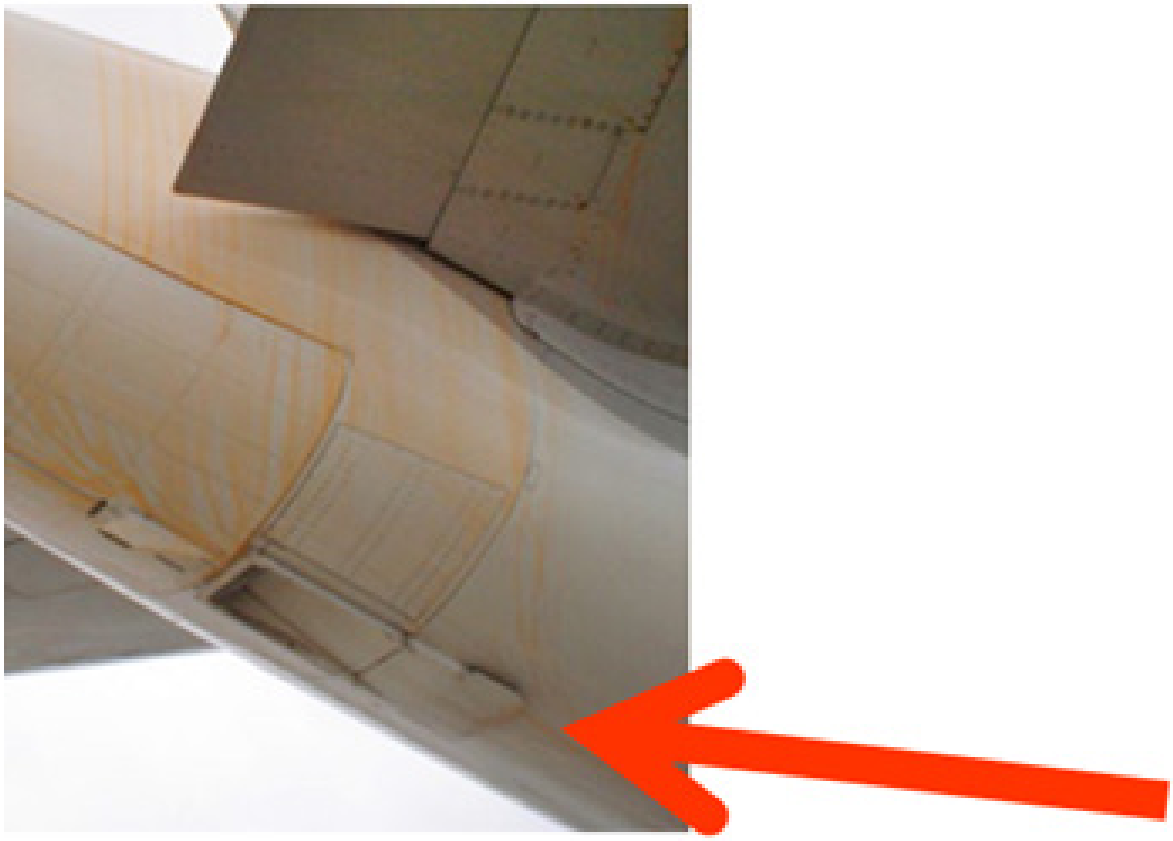


Figure 28 Leakage of deicing fluid on the lower side of the fuselage (Vera-Barcelo 2013).

5 Distribution of Fluids via the Airport Surface

Fuel and oil also leak down onto the airport surfaces. **Figure 29** shows the route of fluids down to the ground and back into the engine.

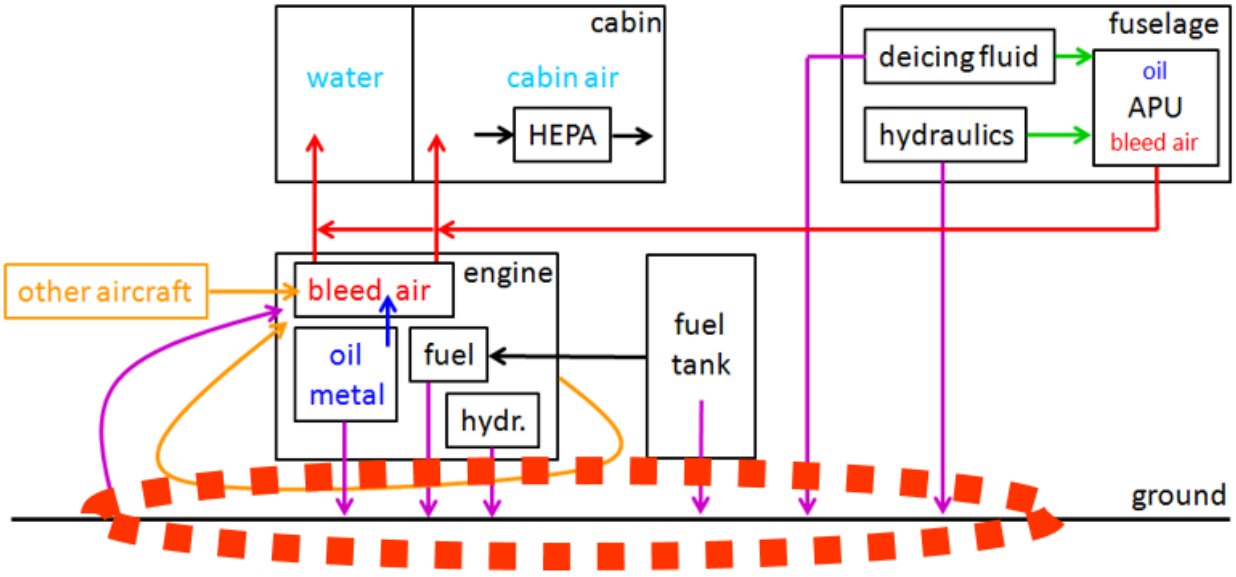


Figure 29 The route of fluids down to the ground and back into the engine.

5.1 Leak Limits of Aircraft Equipment

There are leak limits of aircraft equipment as shown in **Figure 30**. These leak limits show that it is normal for fluids to drip in smaller quantities on the ground. However, an airport sees many airplanes dripping and it all adds up over weeks, months and years.

INSPECT/CHECK	MAXIMUM SERVICEABLE LIMITS
Oil	
The starter pad	7 drops/min
The AGB rear hydraulic pump pad	7 drops/min
The AGB fuel pump pad	7 drops/min
The lube unit pad	No leaks allowed
The main oil/fuel heat exchanger	7 drops/min
The AGB/IDG pad	7 drops/min
The forward sump	20 drops/min
The Aft sump (flooding drain)	Any amount, less than 20 drops/min after engine shutdown.
The Aft sump area	No leak allowed
INSPECT/CHECK	**MAXIMUM SERVICEABLE LIMITS**
Fuel	
The fuel manifold shroud	No leaks allowed
Fuel pump at the AGB drive pad	60 drops/min (up to 90 drops/min allowed for 25 cycles)

Figure 30 A320 leak limits for the CFM56-5B engine in drops per minute. Drops add up over time (Mekanikong 2019c). AGB: Accessory Gearbox.

5.2 Intake of Fluids by the Engine

Fluids that leak on the ground can be ingested by the engine from the ground and can enter the air conditioning system from there. **Figure 31** shows the simulation of two intake vortices, one of them as ground vortex. The rotation of the vortex is visible. **Figure 32** shows the same situation in a photograph.

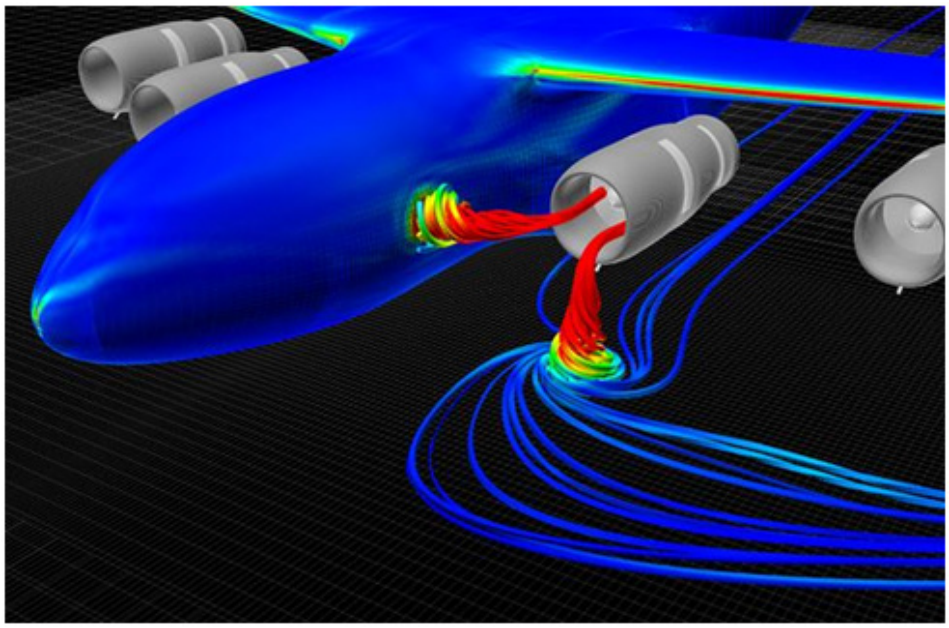


Figure 31 Simulation of two intake vortices, one of them as a ground vortex. The rotation of the vortex is visible. Picture source: https://perma.cc/VH99-87XS.



Figure 32 The ground vortex can also form between the ground and an engine on a high wing (Childs 2017).

6 More Contamination

The location of the recirculation fan of an Airbus A320 is shown in **Figure 33**. The face of the recirculation fan of an Airbus A320 is covered by an oily black soft substance that can be scraped off with a screwdriver (**Figure 34**).

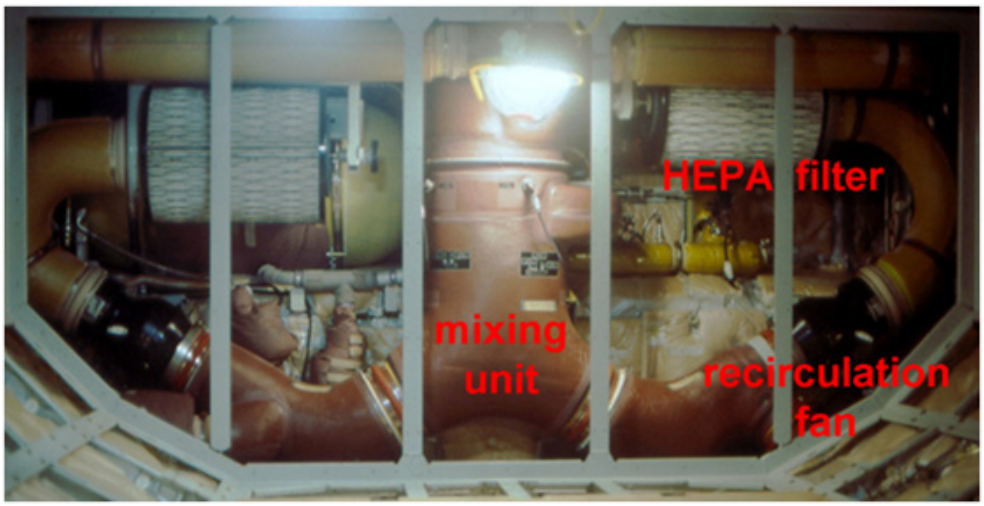


Figure 33 The main component of the Airbus A320 recirculation system. View from the forward cargo compartment looking aft. The wall panels in the cargo compartment are not installed. The support frames for the wall panels are visible. Two HEPA filters and two recirculation fans are installed symmetrically.



Figure 34 The recirculation fan of an Airbus A320 is covered by an oily black soft substance that can be scraped off with a screw driver. Picture source: Video: https://bit.ly/2YXcL3a (English subtitles available). A disassembled recirculation fan is shown on the right.

Figure 35 shows the ambient air inlet in the cargo compartment of the Airbus A320 for cargo compartment heating and ventilation. The inlet is full of moist dust.



Figure 35 The ambient air inlet in the cargo compartment of the Airbus A320 for cargo compartment heating and ventilation. The inlet is full of moist dust.

7 Conclusions

Entropy is the law of nature that states that disorder always increases, as shown in **Figure 36**. This is the reason, why it is impossible to confine engine oil and hydraulic fluids to their (predominantly) closed aircraft systems. This is why engine oil with metal nanoparticles hydraulic fluids, and deicing fluids eventually go everywhere and finally into the human body.

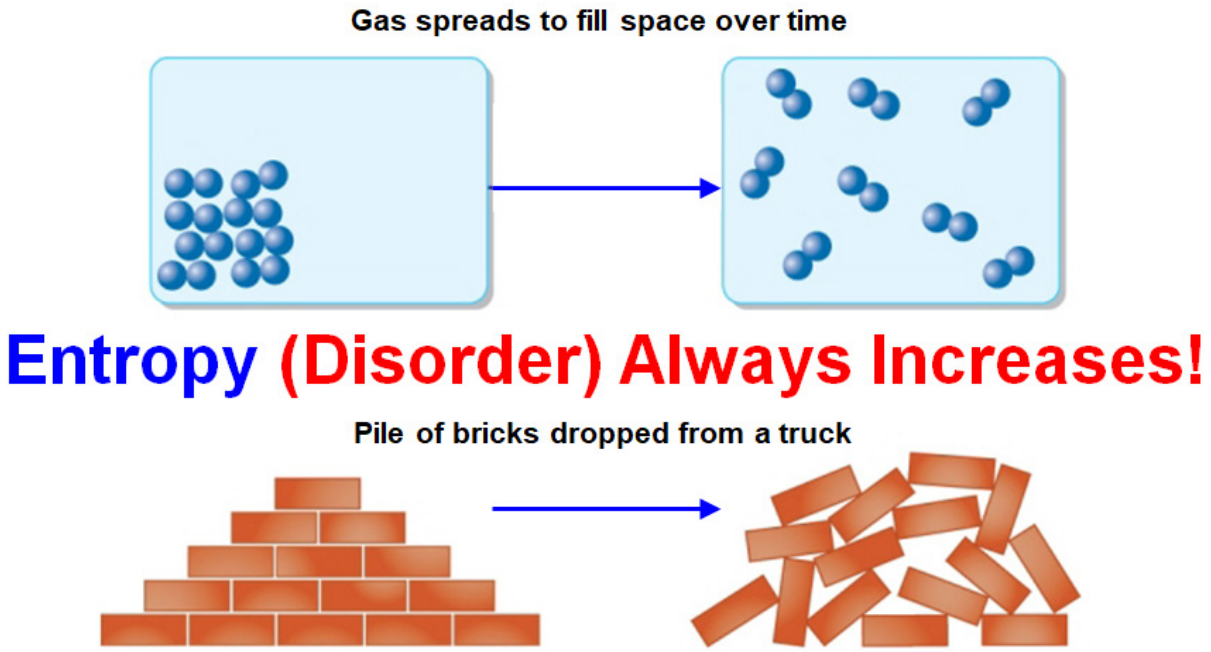


Figure 36 Disorder always increases (based on https://perma.cc/A6KL-XS9R).

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About the Author

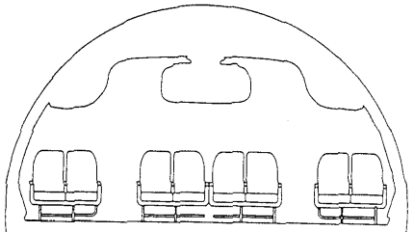
Dieter Scholz is a professor in Aircraft Design, Flight Mechanics, and Aircraft Systems at Hamburg University of Applied Sciences (HAW Hamburg), Germany, where he is head of the Aircraft Design and Systems Group (AERO). He studied Mechanical Engineering at University Hannover, Germany (Dipl.-Ing.) and at Purdue University, USA (MSME). Prof. Scholz was systems engineer at Airbus in Hamburg, Germany and temporary lecturer at Queens University Belfast (QUB), UK. He obtained his Dr.-Ing. (PhD) at Hamburg University of Technology (TUHH). His academic interests include also Flight Testing, Flight Dynamics, Stability and Control, Flight Control and Hydraulic Systems, Aerodynamics, Simulation, Optimization, Short Courses, Open Access Publishing, and questions related to Aviation & Society. Since 2012 this includes also work on the issue of contaminated cabin air. Results are presented on http://CabinAir.ProfScholz.de.

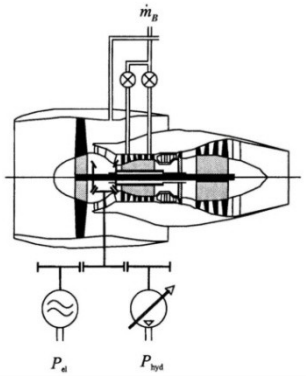
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AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Aircraft Cabin Air and Engine Oil – An Engineering Update

Dieter Scholz Hamburg University of Applied Sciences







https://doi.org/10.5281/zenodo.4743773

International Aircraft Cabin Air Conference 2021

Online, 15 - 18 March 2021

Aircraft Cabin Air and Engine Oil – An Engineering Update

Abstract

Cabin air ventilation in passenger aircraft is done with outside air. At cruise altitude, ambient pressure is below cabin pressure. Hence, the outside air needs to be compressed before it is delivered into the cabin. The most economic system principle simply uses the air that is compressed in the engine compressor anyway and taps some of it off as "bleed air". The engine shaft is supported by lubricated bearings. They are sealed against the air in the compressor usually with labyrinth seals. Unfortunately, the jet engine seals leak oil by design in small quantities. The oil leaking into the compressor contains toxic additives. Furthermore, the oil includes toxic metal nanoparticles – normal debris from the engine. An alternative source for the compressed air is the Auxiliary Power Unit (APU). Like the aircraft's jet engine, it is a gas turbine, built much in the same way when it comes to bearings and seals. For this reason, also compressed air from the APU is potentially contaminated in much the same way. Compressed air from the engine is also used to pressurize the potable water. It has been observed that the potable water on board can also be contaminated. Fan air and bleed air ducts at the interface between engine and wing carry outside compressed air. The inside of the ducts shows differences. The brown stain in the bleed air duct appears to be engine oil residue. In comparison, the fan air duct is clean. This shows that oil leaves the compressor bearings. Ducting further downstream shows a black dry cover. The reason for the change in color seems to result from the different air temperatures: 400 °C at engine outlet and 200 °C further downstream behind the precooler. The water extractor is a part of the air conditioning pack. The inlet of the water extractor is covered with black oily residue, because the temperature is even lower at this point. The air conditioning air distribution ducts in the cabin are black inside from contaminated bleed air. New ducts are clean. Air duct are even clean inside at the end of the aircraft's life, in areas where they are used such that no bleed air flows through them. Flow limiters have been found in ducts of the air conditioning system that are clogged from engine oil. Also riser ducts feeding the cabin air outlets are black inside from engine oil residue. Cleaning on top of the overhead bins brings to light dirt that is clearly more than dust. The black residue known from the ducts settles also on the bin surface. Deicing fluid and hydraulic fluid can find their way into the air conditioning system via the APU air intake. A fence and a deflector around the air intake cannot fully prevent contaminants from entering the APU. Traces of contamination tend to be visible on the lower part of the fuselage. Contaminants are carried by the air flow in flight, from the landing gear bay to the APU inlet. Hydraulic systems are never leak free. A hydraulic seal drain system tries to collect hydraulic fluid leaving the system with partial success. It is impossible to catch all leaking hydraulic fluid. If the containers of the seal drain system are not emptied they spill over. In old aircraft, surfaces in the landing gear bay are covered with a layer of hydraulic fluid. Dirt accumulates on the sticky surface. The hydraulic fluid is not confined to the inside of hydraulic bays, but continues its journey on the lower side of the fuselage towards the APU. Deicing fluid if applied in the winter to the aircraft and can leak from the tail into the APU inlet. Fuel and oil also leak down onto the airport surfaces. These fluids can be ingested by the engine from the ground and can enter the air conditioning system from there. Entropy is the law of nature that states that disorder always increases. This is the reason, why it is impossible to confine engine oil and hydraulic fluids to their (predominantly) closed aircraft systems. This is why engine oil with metal nanoparticles hydraulic fluids, and deicing fluids eventually go everywhere and finally into the human body.

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- Distribution of Engine Oil with Metal Nanoparticles
- Distribution of Hydraulic and Deicing Fluid
- Distribution of Fluids via the Airport Surface
- Entropy – Distribution by Law of Nature

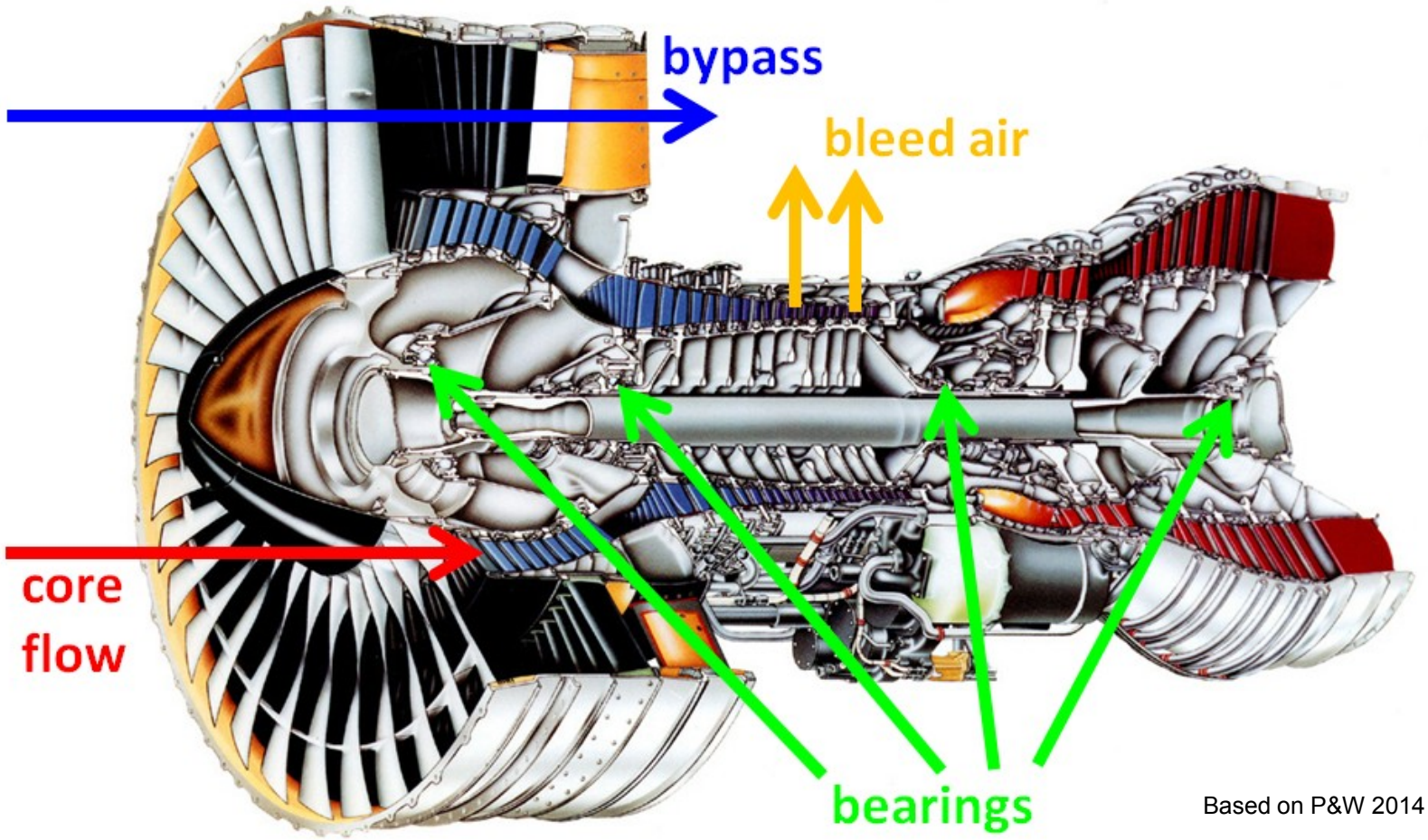
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Jet Engine Technology & Results

Jet Engine Technology & Results

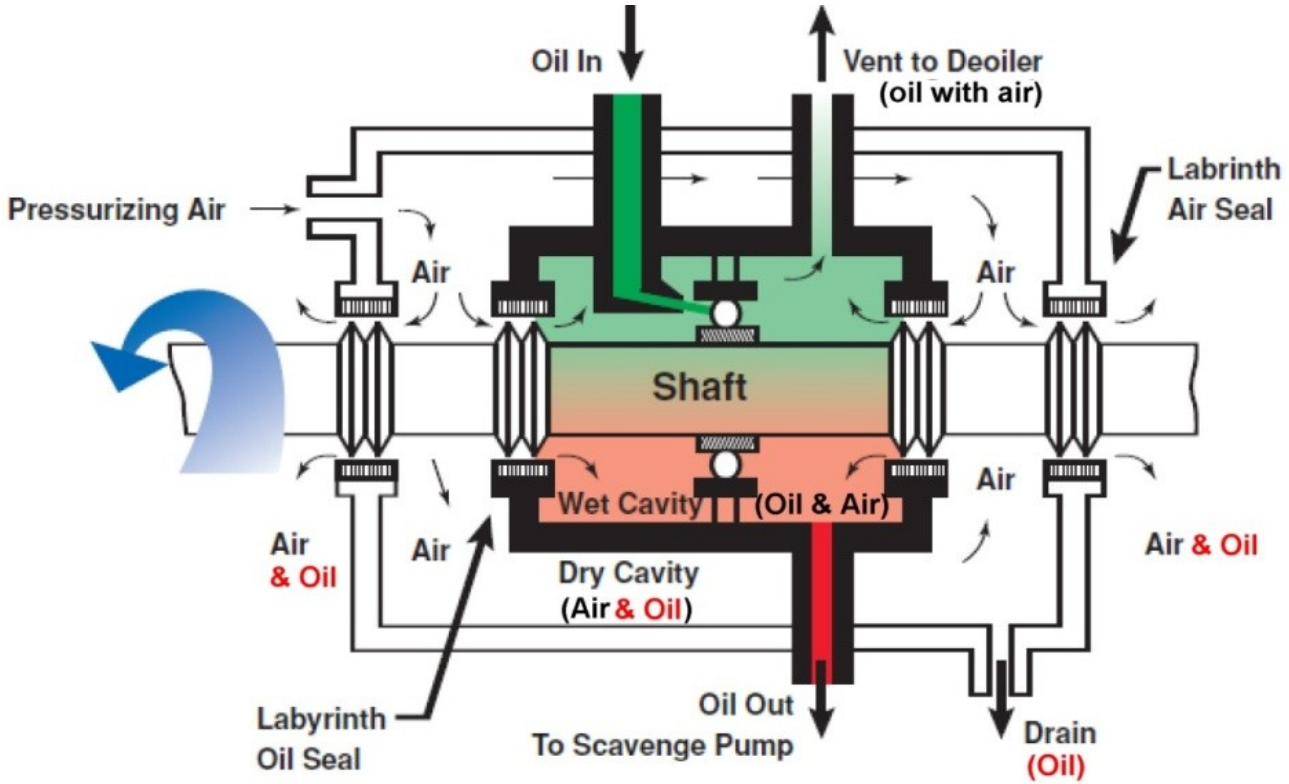
Engine Bearings and Bleed Air



Based on P&W 2014

Jet Engine Technology & Results

Lubrication and Sealing of Engine Bearings



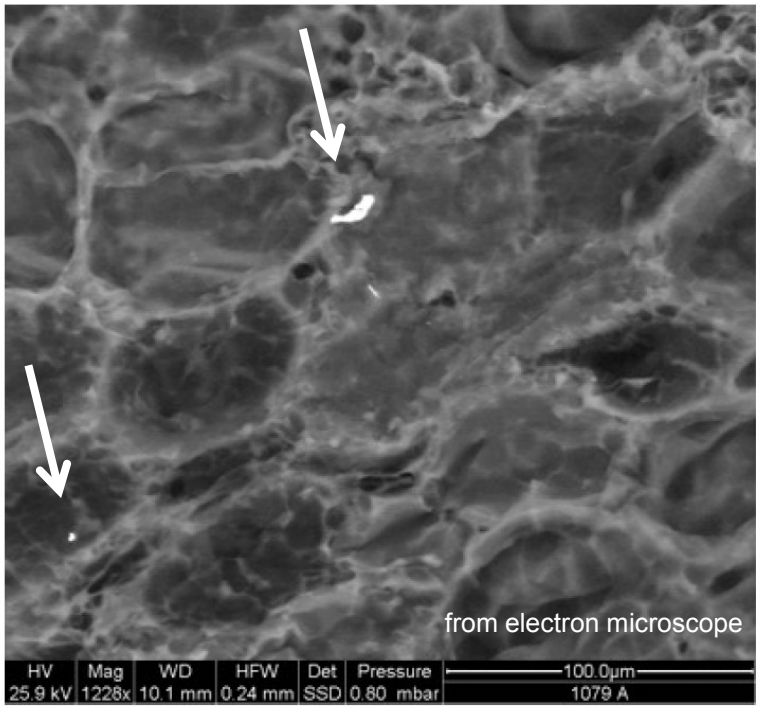
Based on Exxon 2017

Normal operation of engine seals:

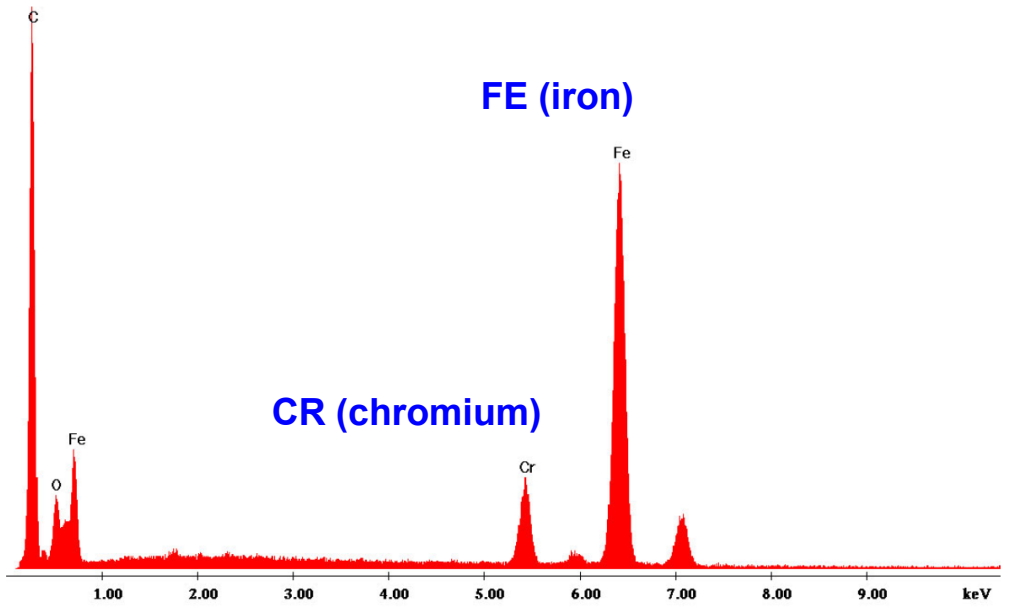
1. The "**drain**" discharges **oil**.
2. The "**dry cavity**" contains **oil**.
3. Air and **oil** leak from bearings **into** the **bleed air**.

=> **Engines leak small amounts of oil by design!**

Metal Nanoparticles in the Oil – Finally in Human Fatty Tissue of Aviation Employees



(Gatti 2019, report written for client)

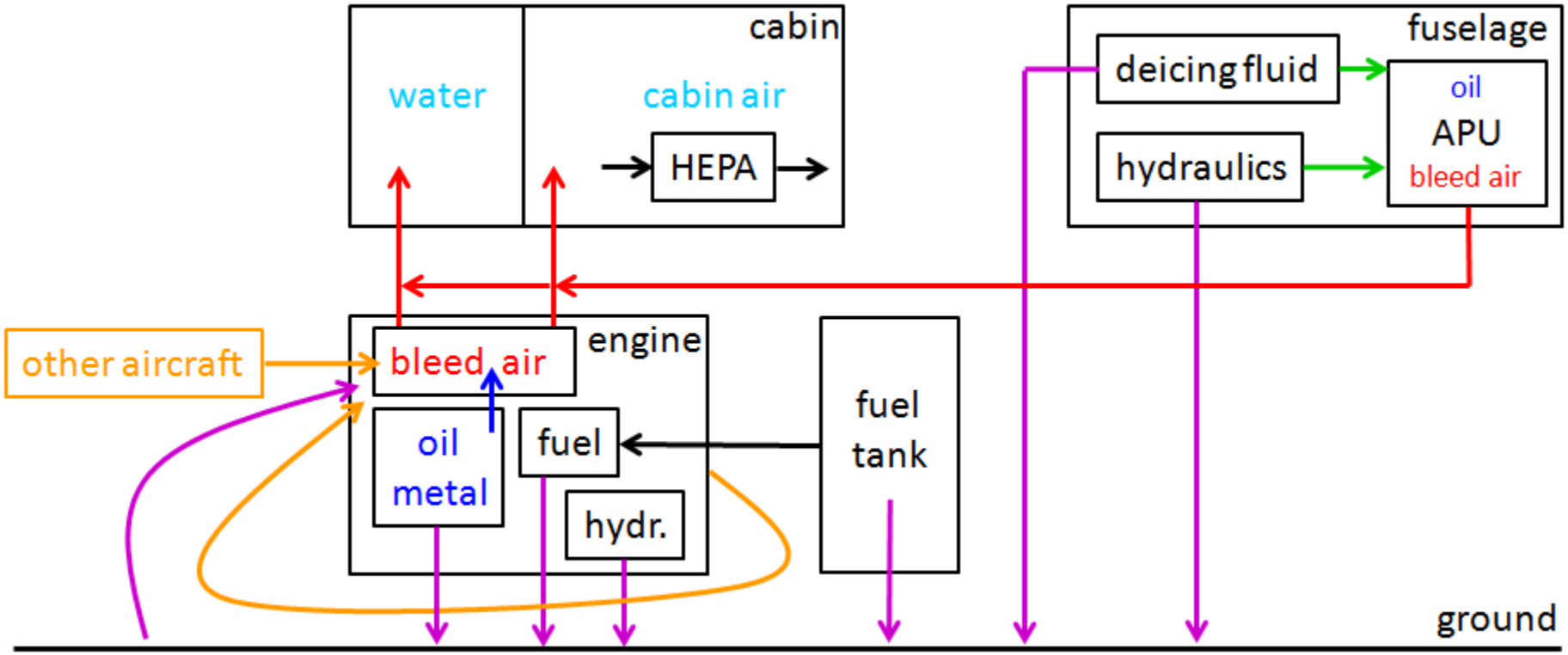


Analysis 8 of Table I. High-magnification image (1228x) and EDS spectrum of 10-micron and 1-micron brighter-looking particles composed of Carbon, Iron, Chromium and Oxygen: a stainless-steel composition. EDS: Energy-Dispersive X-ray Spectroscopy.

Distribution of Engine Oil with Metal Nanoparticles

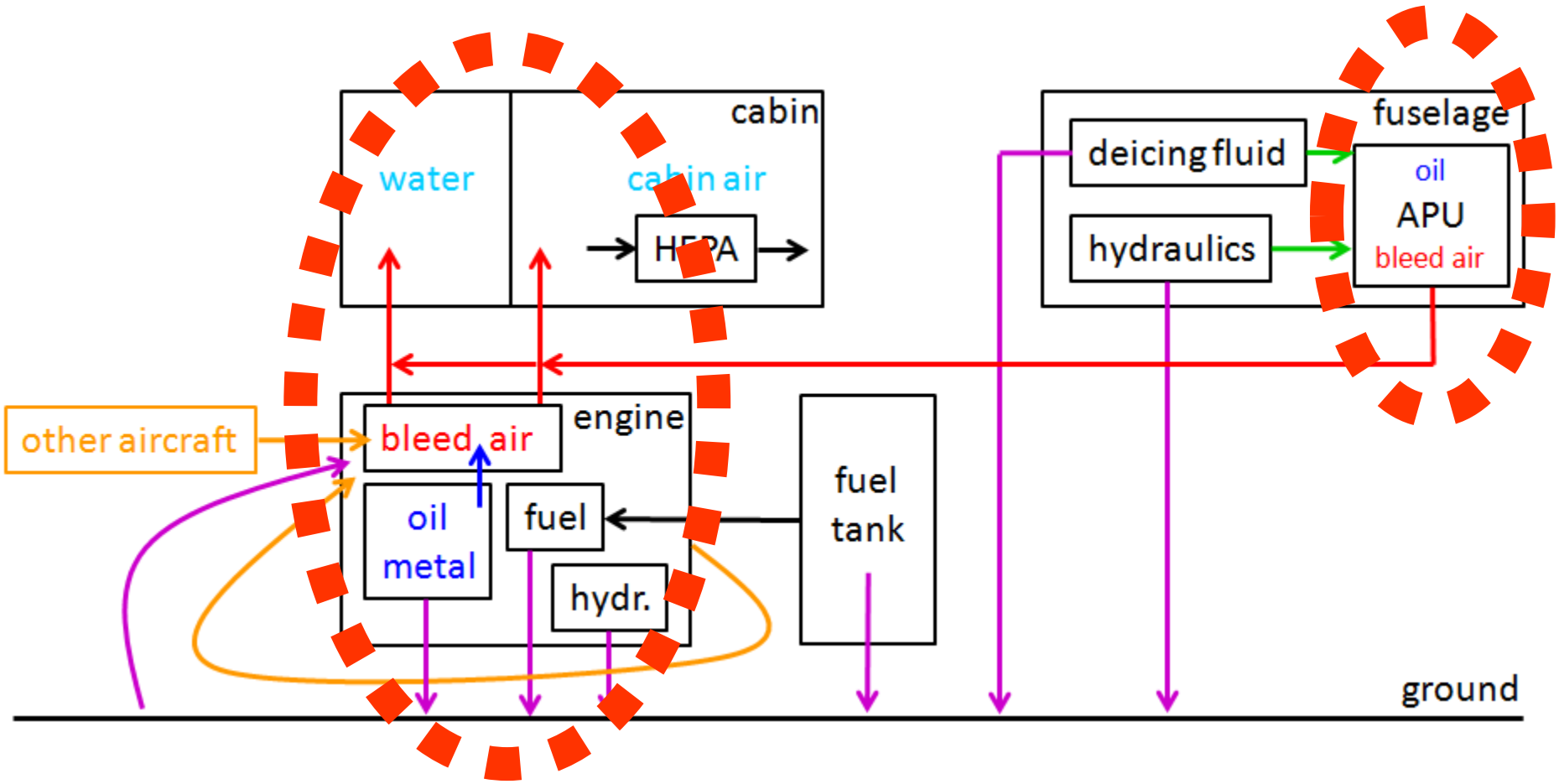
Distribution of Engine Oil with Metal Nanoparticles

Contaminants and Their Routes Into the Cabin



Distribution of Engine Oil with Metal Nanoparticles

The Route of Engine Oil Into the Cabin



Distribution of Engine Oil with Metal Nanoparticles

Cabin Air Contamination Event Due to Engine Oil After Technical Fault



Top: 2010-09-17, US Airways US-432, Boeing 757-200. Bottom: 2018-12-10, Indigo flight 6E-237, Airbus A320neo.

Distribution of Engine Oil with Metal Nanoparticles

Cabin Air Contamination Event Due to Engine Oil After Technical Fault



Top:2019-08-22, Hawaiian Airlines HA47, A321neo. Bottom: 2019-08-05, British Airways BA-422, Airbus A321.

Distribution of Engine Oil with Metal Nanoparticles

Engine Oil in the Potable Water

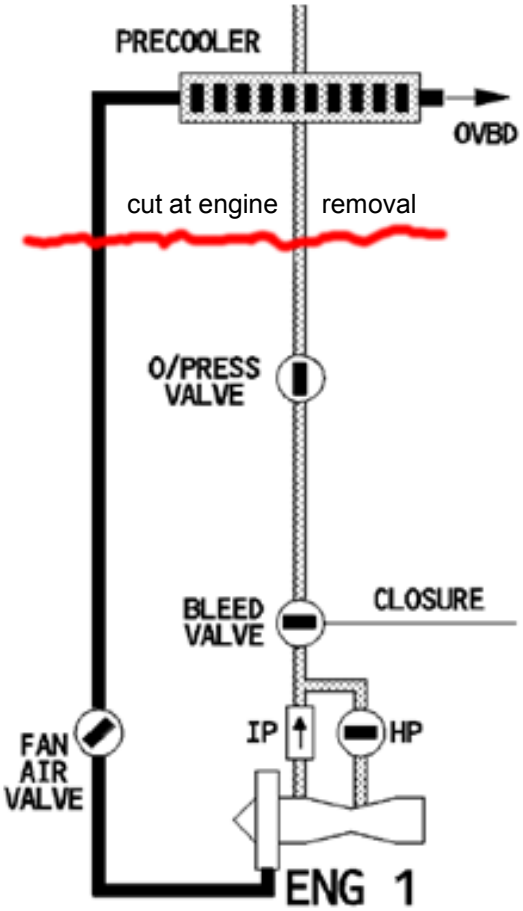


Potable water contaminated by bleed air on an Airbus A320. The last water extracted from the tank before it is empty is black, probably from engine oil residue.

Picture source:
Video: https://youtu.be/dlPOeudTTCI.
The video explained:
https://purl.org/CabinAir/WaterContamination.

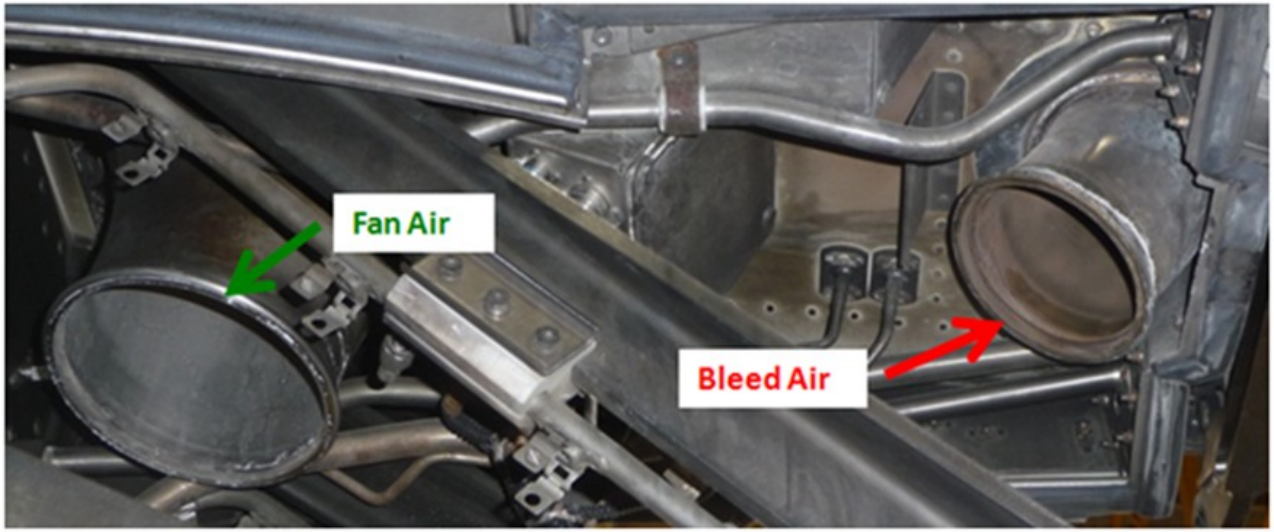
Distribution of Engine Oil with Metal Nanoparticles

Engine Oil Colors Bleed Air Duct Brown



Airbus A320 FCOM

Fan air and bleed air ducts at the interface between engine and wing on an Airbus A320. The brown stain in the bleed air duct appears to be engine oil residue. In comparison, the fan air duct is clean. Air temperature in the bleed air duct about 400 °C.



Distribution of Engine Oil with Metal Nanoparticles

Engine Oil Colors Bleed Air Duct Black

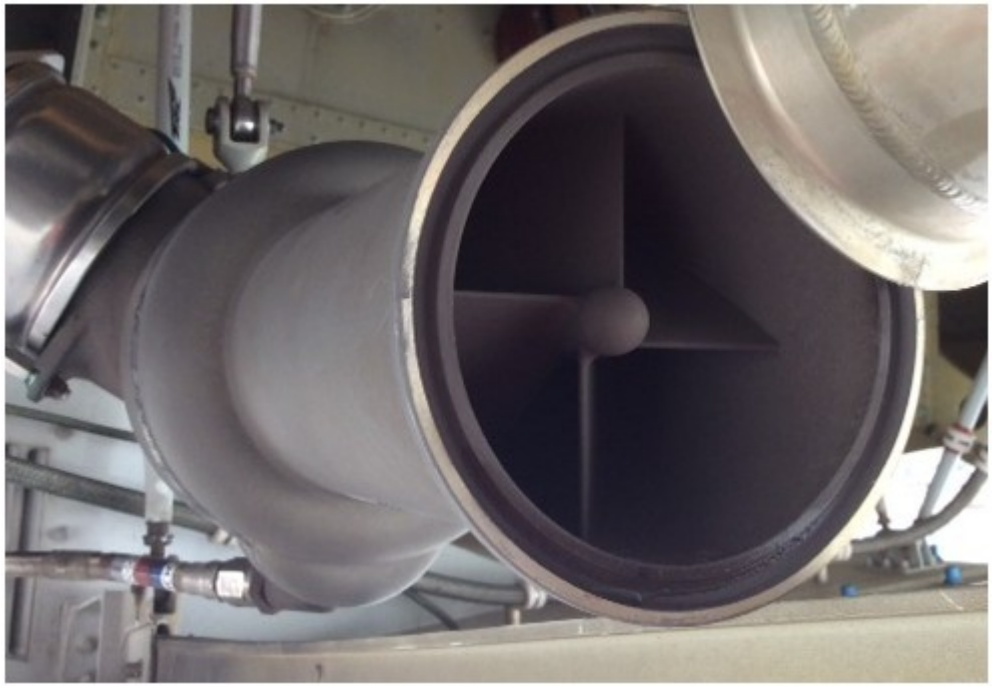


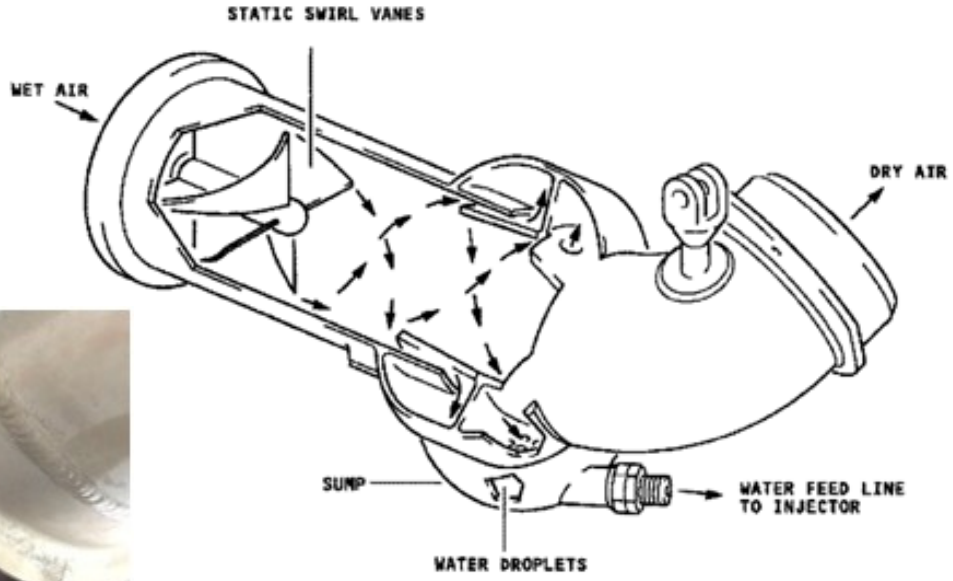
Bleed air duct of a Boeing 737 with black oil residue inside. Air temperature of about 200 °C.

Picture source: **Video**: https://vimeo.com/groups/617439/videos/345959025

Distribution of Engine Oil with Metal Nanoparticles

Engine Oil Residue Accumulates in Water Extractor





The Airbus A320 water extractor (Airbus 1999), is a part of the air conditioning pack. The inlet of the water extractor is covered with black oily residue.

Distribution of Engine Oil with Metal Nanoparticles

Engine Oil Colors Cabin Air Duct Black





Airbus A320 air conditioning air distribution duct in the cabin. The inside is black from contaminated bleed air.

Distribution of Engine Oil with Metal Nanoparticles

Air Duct Is Clean at End of Life of an Aircraft, if Not Fed With Bleed Air



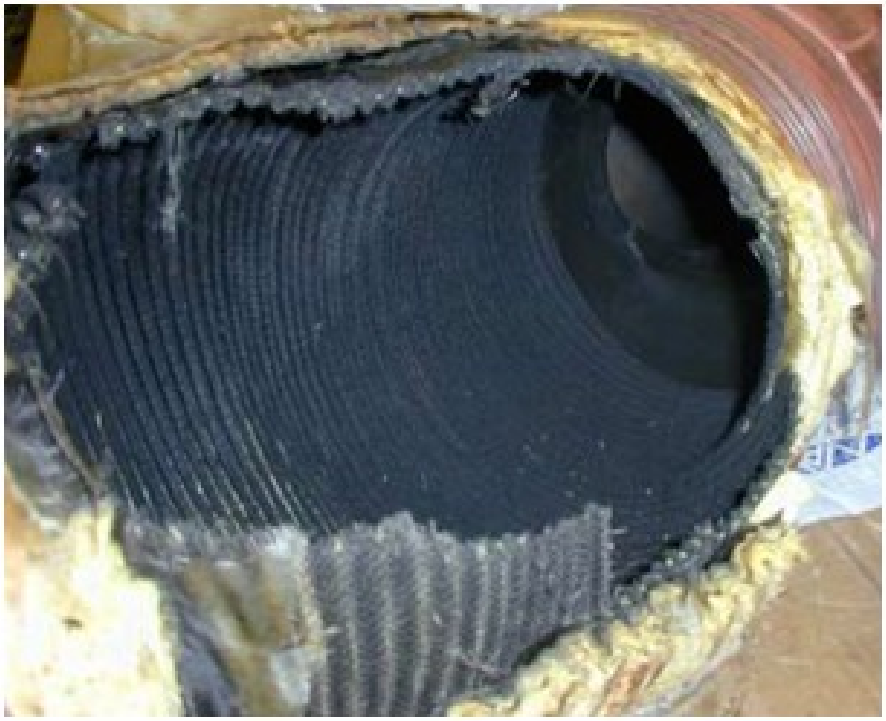
The inside of the air extract duct (located near the extract fan) is clean at the end of life of an Airbus A320, because the duct is normally not fed with bleed air.



Distribution of Engine Oil with Metal Nanoparticles

Engine Oil Colors Cabin Air Duct Black





Left: A unused duct supplied new.
Right: A ducts that had been installed downstream of the environmental control system air conditioning packs on a BAe 146 passenger aircraft after 26061 flight hours (CAA 2004).

Distribution of Engine Oil with Metal Nanoparticles

Flow Limiter in Air Conditioning Ducts Clogged





Flow limiter clogged from pyrolysed engine oil in ducts of the air conditioning system of Boeing 757 aircraft with Rolls-Royce RB211-535E4 engines operated by Icelandair (Hansen 2019) compared to a clean flow limiter (top).





Distribution of Engine Oil with Metal Nanoparticles

Engine Oil Colors Riser Ducts Black





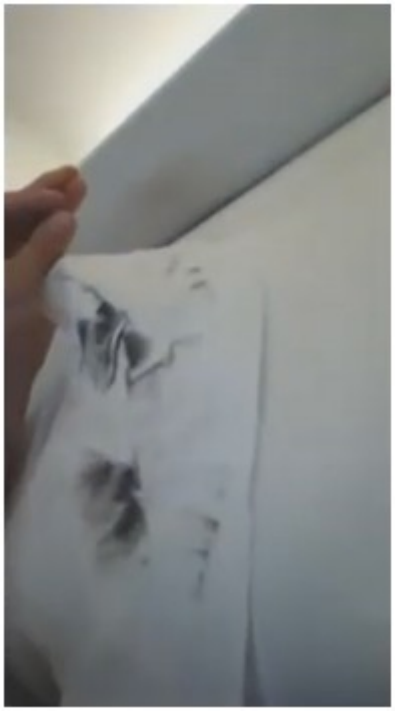
Video:
https://bit.ly/2YXcL3a

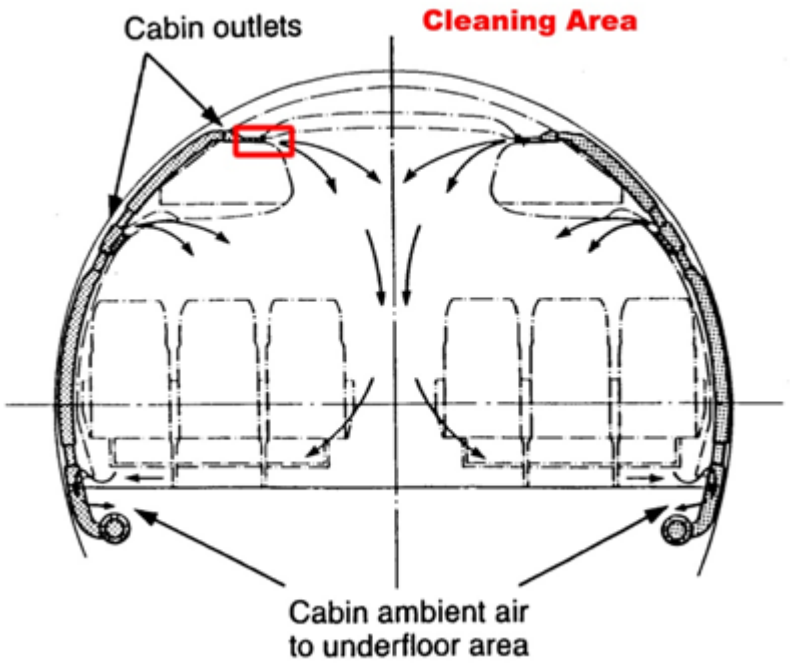


Riser ducts and lower cabin air outlet on an Airbus A320 aircraft. The red line close to the cabin floor shows, where the duct was separated and opened. It is black inside from engine oil residue.

Distribution of Engine Oil with Metal Nanoparticles

Black Residue Settles on the Overhead Bin's Surfaces



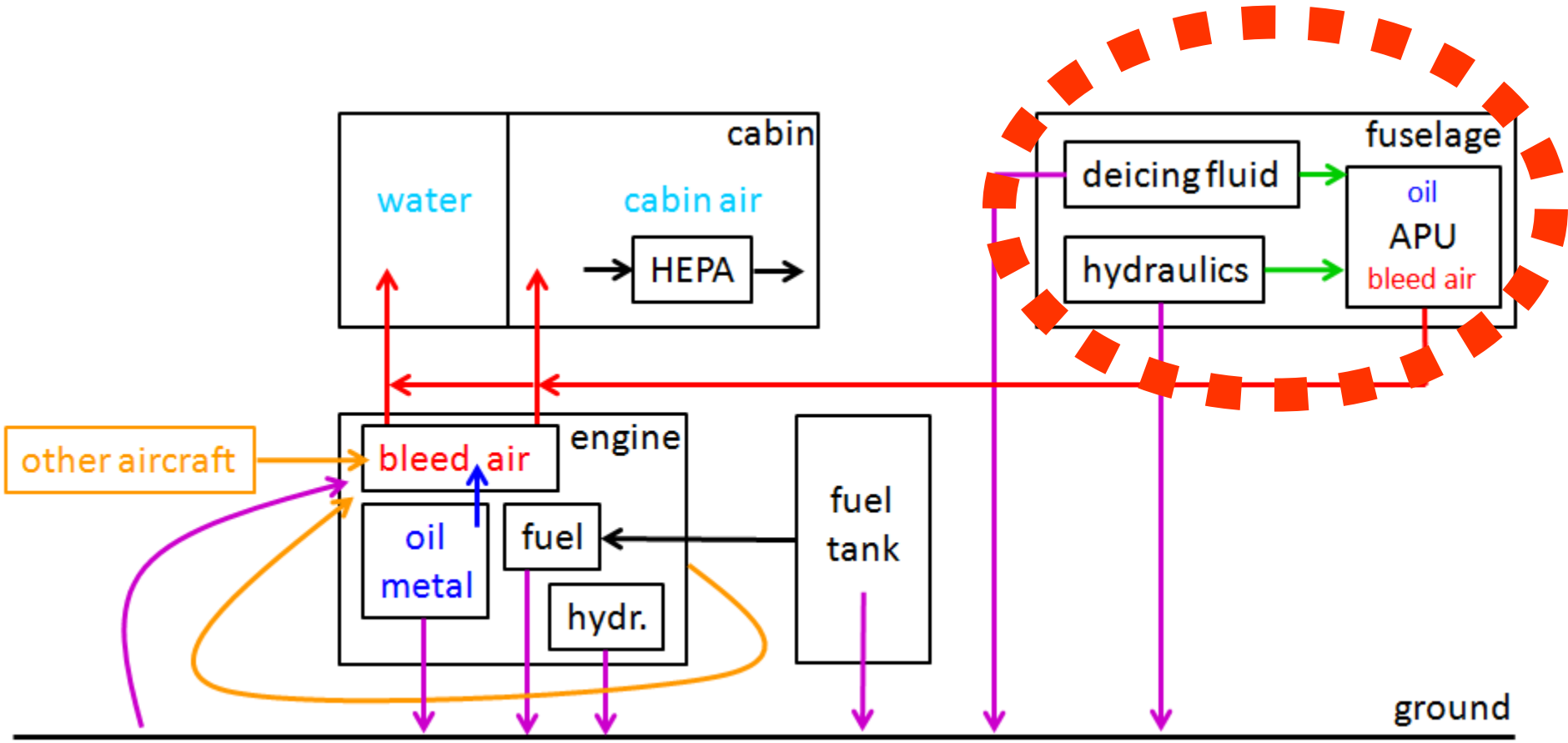


Left: Cleaning on top of the overhead bins of an Airbus A320 brings to light dirt that is clearly more than dust. The black residue known from the ducts settles also on the bin surface. Picture source: **Video**: https://youtu.be/uQfA_DiMBS8
Right: Airbus A320 cabin cross section with the upper cabin air outlet releasing potentially contaminated air on top of the overhead bins (Airbus 1999).

Distribution of Hydraulic and Deicing Fluid

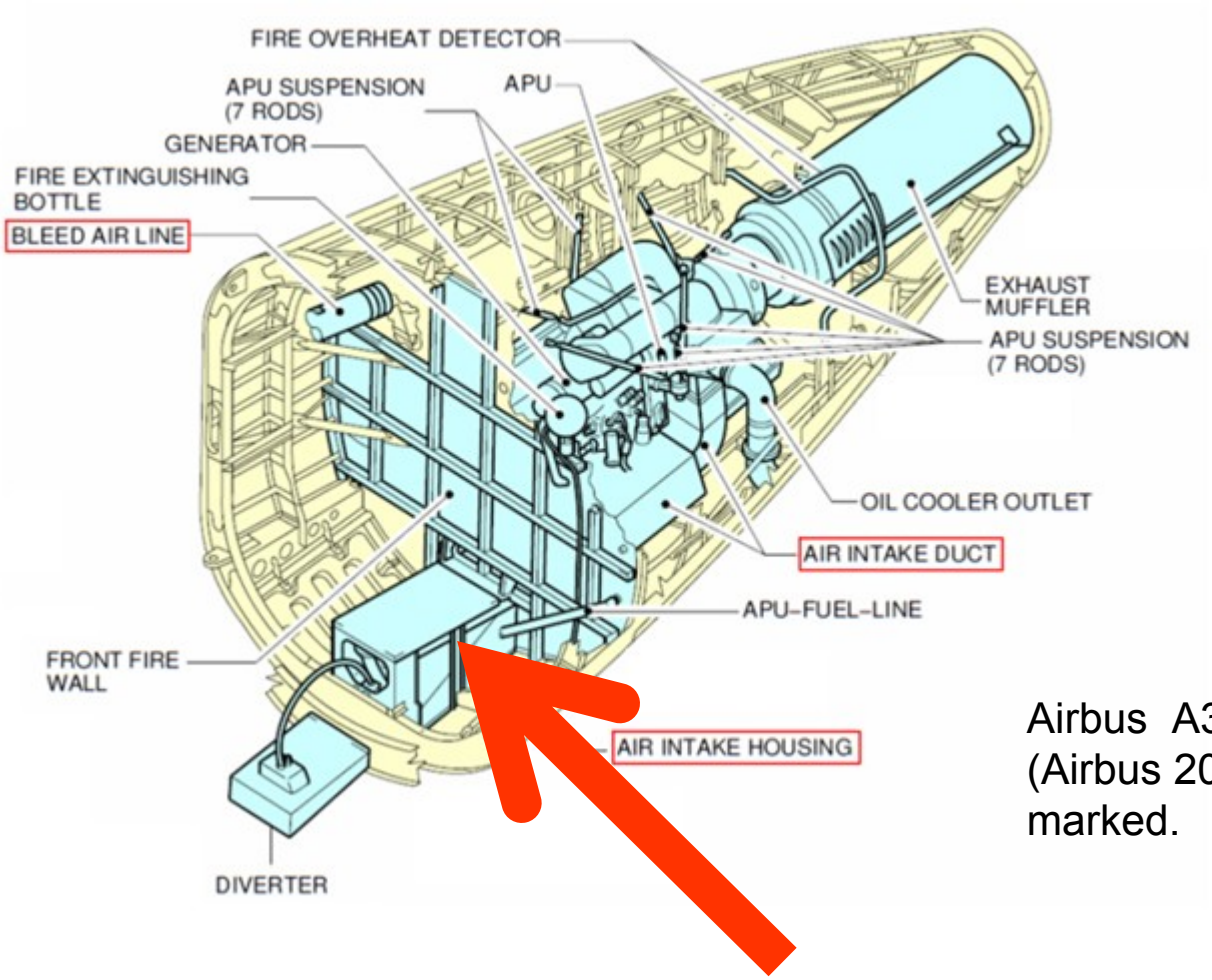
Distribution of Hydraulic and Deicing Fluid

The Route of Hydraulic and Deicing Fluid into the Cabin



Distribution of Hydraulic and Deicing Fluid

APU Air Intake – Entry Point for Hydraulic and Deicing Fluid into the Cabin



Airbus A320 APU installation (Airbus 2020). The air intake is marked.

Distribution of Hydraulic and Deicing Fluid

APU Air Intake – Entry Point for Hydraulic and Deicing Fluid into the Cabin





Left: Air intake of the A320 APU. Fence and deflector around the APU air intake are clearly visible. These measures cannot fully prevent contaminants from entering the APU. Right: Traces of contamination are clearly visible on the lower part of the fuselage. Carried by the air flow in flight, the contaminants reach the APU inlet. Source of picture on the right: Airbus 2019.

Distribution of Hydraulic and Deicing Fluid

"Zero Leakage" of Hydraulic Systems Has Not Been Achieved





Mekanikong 2019a

Aft collector tank of the A320 hydraulic seal drain system. In this old Airbus A320, **all surfaces** in the landing gear bay **are covered with a layer of hydraulic fluid**. Dirt accumulates on the sticky surface. The hydraulic fluid is not confined to the inside of the hydraulic bay, but continues its journey on the lower side of the fuselage towards the APU inlet (previous page).

Distribution of Hydraulic and Deicing Fluid

Deicing Fluid Leaks from the Tail into the APU Inlet



Vera-Barcelo 2013

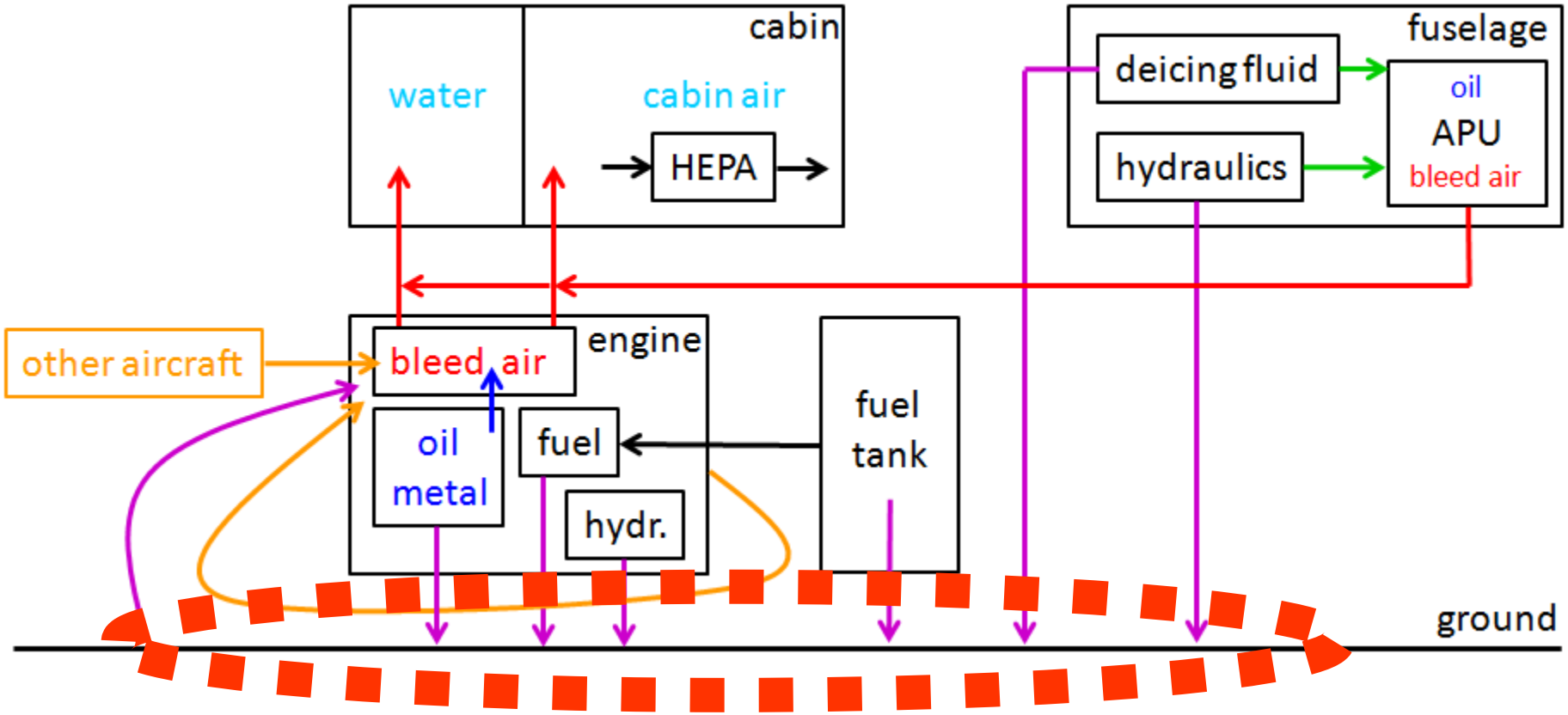


Petchenik 2015

Distribution of Fluids via the Airport Surface

Distribution of Fluids via the Airport Surface

The Route of Fluids Down to the Ground and Back into the Engine



Distribution of Fluids via the Airport Surface

Leak Limits of Aircraft Equipment (Example)

INSPECT/CHECK	MAXIMUM SERVICEABLE LIMITS
Oil	
The starter pad	7 drops/min
The AGB rear hydraulic pump pad	7 drops/min
The AGB fuel pump pad	7 drops/min
The lube unit pad	No leaks allowed
The main oil/fuel heat exchanger	7 drops/min
The AGB/IDG pad	7 drops/min
The forward sump	20 drops/min
The Aft sump (flooding drain)	Any amount, less than 20 drops/min after engine shutdown.
The Aft sump area	No leak allowed
INSPECT/CHECK	**MAXIMUM SERVICEABLE LIMITS**
Fuel	
The fuel manifold shroud	No leaks allowed
Fuel pump at the AGB drive pad	60 drops/min (up to 90 drops/min allowed for 25 cycles)

A320 leak limits for the CFM56-5B engine in drops per minute. Drops add up over time (Mekanikong 2019b).

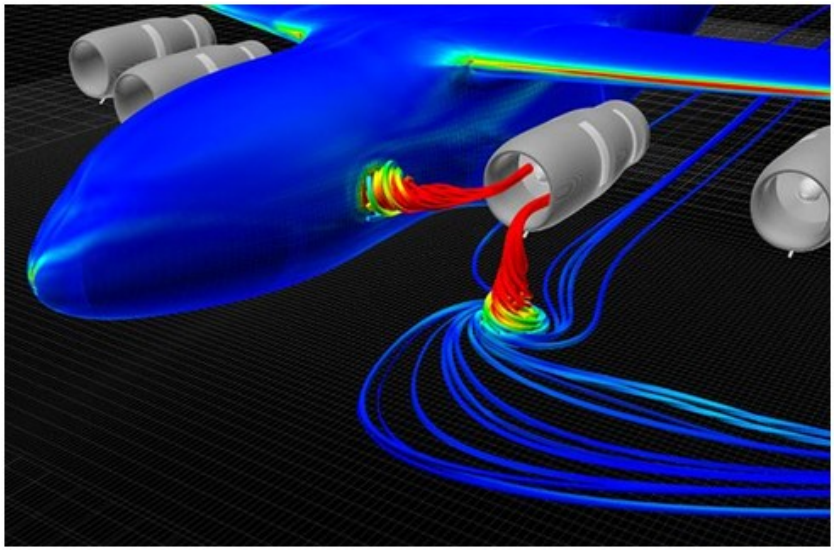
AGB: Accessory Gearbox

Distribution of Fluids via the Airport Surface

Fluids Can Be Ingested by the Engine from the Ground



The ground vortex can also form between the ground and an engine on a high wing (Childs 2017).

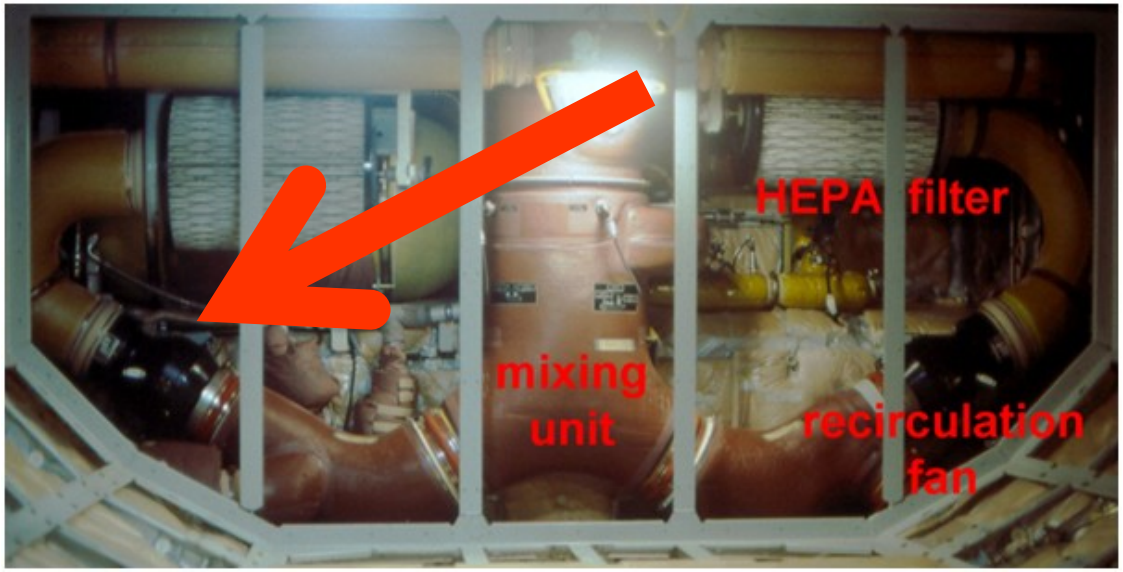


Simulation of two intake vortices, one of them as a ground vortex. The rotation of the vortex is visible (https://perma.cc/VH99-87XS).

More Contamination

More Contamination

Contaminated Recirculation Fan



The face of the recirculation fan of an Airbus A320 is covered by an oily back soft substance that can be scraped off with a screw driver. Picture source: **Video**: https://bit.ly/2YXcL3a





More Contamination

Contaminated Cargo Compartment Heating



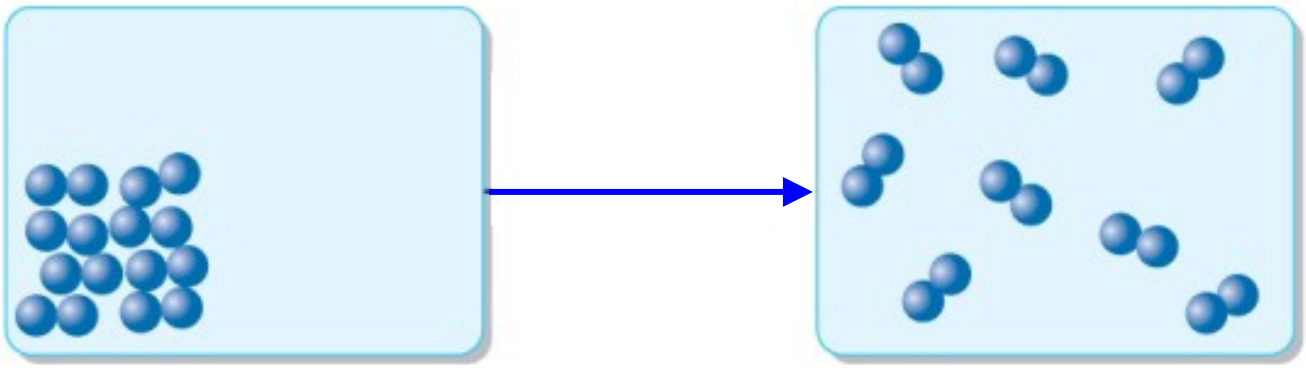
The ambient air inlet in the cargo compartment of the Airbus A320 for cargo compartment heating and ventilation. The inlet is full of moist dust.

Entropy – Distribution by Law of Nature

Entropy – Distribution by Law of Nature

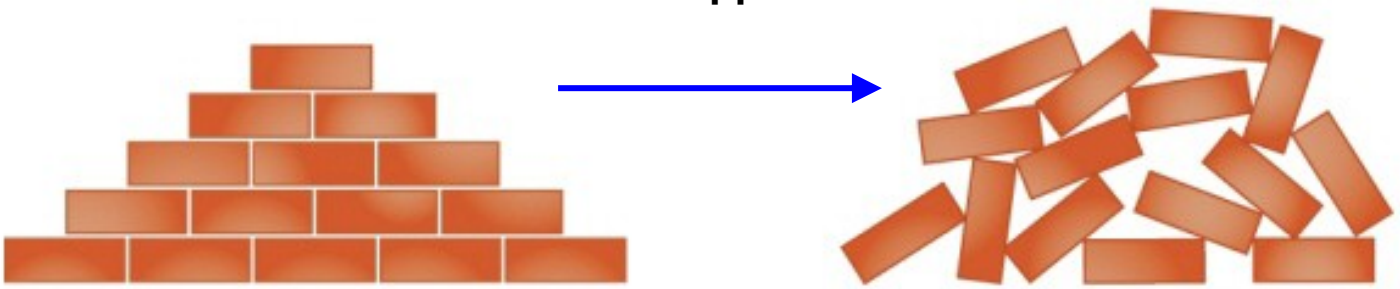
Contaminants Spread Everywhere

Gas spreads to fill space over time



Entropy (Disorder) Always Increases!

Pile of bricks dropped from a truck



Entropy – Distribution by Law of Nature

Contaminants Spread Everywhere

Entropy is the law of nature
by which ...

- **engine oil with metal nanoparticles**
- **hydraulic fluid**
- **deicing fluid**

goes everywhere and finally
into the human body.

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Cabin Air Contamination – A Summary of Engineering Arguments

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SCHOLZ, Dieter, 2018. Technical Solutions to the Problem of Contaminated Cabin Air. German Aerospace Congress, Friedrichshafen, Germany, 04.-06.09.2018. Presentation No. 0270.
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Aircraft Cabin Air International Conference 2021 (ACA 2021) – Proceedings

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Editors: Dieter Scholz, Susan Michaelis

Radial Lip Seals for Aerospace Applications – An Overview

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Extended Abstract

A seal is a component that impedes the flow of fluid through a given system. The word 'impede' holds emphasis as there is no such thing as a zero leakage seal. All dynamic seals must leak, even if it is as low as 1 mm^3 per year and referred to as 'emission' (Flitney 2014).

Since the 1700's, seals have continued to evolve and develop in their design, geometries and materials. The design of the radial lip seal has evolved from oil resistant leather to synthetic rubber and eventually, replaced by high temperature elastomers. The 1980's saw the revolution of the radial lip seal from a single commodity seal to a 'sealing system', which included the housing bore, shaft, lubricant along with several operational factors.

Radial lip oil seals are rotary shaft seals placed on a shaft, usually with an interference fit and are used in both static and dynamic sealing applications. They aim to prevent unintended leakage of oil past the seal and prevent debris from entering the system. Their design usually includes a sealing lip and a dust lip to achieve these goals. The sealing lip slides on the surface of the shaft and achieves sealing with the help of a garter spring with a pre-load. Such seals usually rely on a thin film of lubricant, around 2-5 microns in thickness, in between the seal and shaft surface to operate. The sealing system, thus, consists of three components: seal, lubricant film and shaft. The interface between the seal and shaft is one that is most interesting as it is where the actual sealing takes place.

There is no such thing as a perfect sealing system – the requirements for each application will dictate the design and selection of a seal used. Seals are subject to harsh environmental conditions including high temperatures, high pressures, system vibration, shaft-run out and misalignment. These conditions will influence the fatigue, wear, friction, lip temperature, surface polish and leakage at the sealing interface. Often, not all these conditions can be avoided and it is up to the engineer to make selections for the elastomer material, filler content, shaft coating, and other factors based on the needs of that system. Reducing wear and friction in a system for longer seal life can result in accepting some leakage in the system. In contrast, to reduce leakage of oil in a system, we must often accept that the seal can experience pre-mature wear if it runs dry.

The standards DIN 3760, DIN 3761-1 and ISO 6194-1 specify the state-of-the-art design of radial lip seals, the housing bore, shaft, lubricant and operating conditions. In addition to specific requirements for the seal itself, the standards also specify several factors to consider for all the remaining elements of the system. The use of a sleeve

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Related presentation: https://doi.org/10.5281/zenodo.5511963
Review process: Editorial review. The corresponding author is marked with *.

fitted on the shaft is common as surface treating large shafts is expensive and cumbersome. They fit onto the shaft and rotate along with it. In instances of significant wear or damage, simple replacement of the sleeve is only required.

Radial lip oil sealing systems show a high complexity. Important are the specifications and standards for lip oil seals. Even so, storage and installation of these seals can also affect their performance as they are easily damaged. The significance of seals is high, because their failure can pose a potential threat to the over-all safety of the aircraft. Safety is the common denominator for all stakeholders in the aerospace industry. This shows the general importance of sealing elements in aerospace applications and the potential detrimental consequence of their failure.

Three examples of aircraft seal failure demonstrate the significance of general sealing components by showing how varying degrees and types of seal failure has threatened their safety. While different seals are failing in varying incidents, the point is to draw attention to the significance of these inexpensive components that are critical in nature. The three cases should be pointed out: 1.) Airbus A320neo P&W: 2017-2018, 2.) Airbus A330-323 P&W turbofan engines: 2016 and 3.) Airbus A320 IAE/P&W: 2014.

1.) This problem came about in early 2018 with P&W's new GTF engine (geared turbofan engine) for the Airbus A320neo. A design flaw discovered in January 2018 on approximately 100 of these engines, some of which were in the Airbus assembly plant and others in service, resulted in recalling these engines. This was because four aircraft engines experienced sudden shutdowns during take-off or during flight. The root cause of the engine shut down was the knife-edge seal (similar design to the labyrinth seal, patented by P&W). It was said by the Chief Executive that fixing this faulty seal would cost the company $50 billion and increase the company's losses on geared turbofan engine deliveries closer to $1.2 billion (Trimble 2018, Bogaisky 2018a, Bogaisky 2018b).

2.) During boarding of a flight from London Heathrow Airport, the aircraft cabin filled up with smoke, resulting in immediate evacuation of all passengers. The source of this smoke traced back to a failure of the Auxiliary Power Unit (APU) compressor carbon seal (carbon seals are also known as mechanical seals). This resulted in oil leakage and contamination of the bleed air supply. Metallic debris found in the shared oil system compromised the load compressor bearing, resulting in failure of the compressor carbon seal. The report also mentions that the APU manufacturer had experienced similar events prior to this one where failure caused oil entering the bleed air system through the load compressor carbon seal (AAIB 2017).

3.) This flight from Cochin to Delhi by Air India experienced uncontained engine failure in flight and a fire confined to engine 2 only. Cause of this incident led back to inadequate overhaul practices of the oil seal during maintenance procedures. During overhaul, the #4 bearing seal underwent a lapping process (superfinishing process of the surface). The anti-weep grooves, present to prevent the oil from escaping the compartment during sub idle conditions, were not cleaned and inspected properly. This resulted in blockage of the grooves with lapping debris. As a result, the oil escaped the #4 bearing compartment and went into the high-pressure turbine (HPT). Eventually, this compromised the air seal placed at the turbine, causing low cycle fatigue fracture of the second stage air seal at high temperatures and damaging the turbine blades. Two of the seals in two different places in the engine experiencing failure resulted in the engine fire (AAIB 2014).

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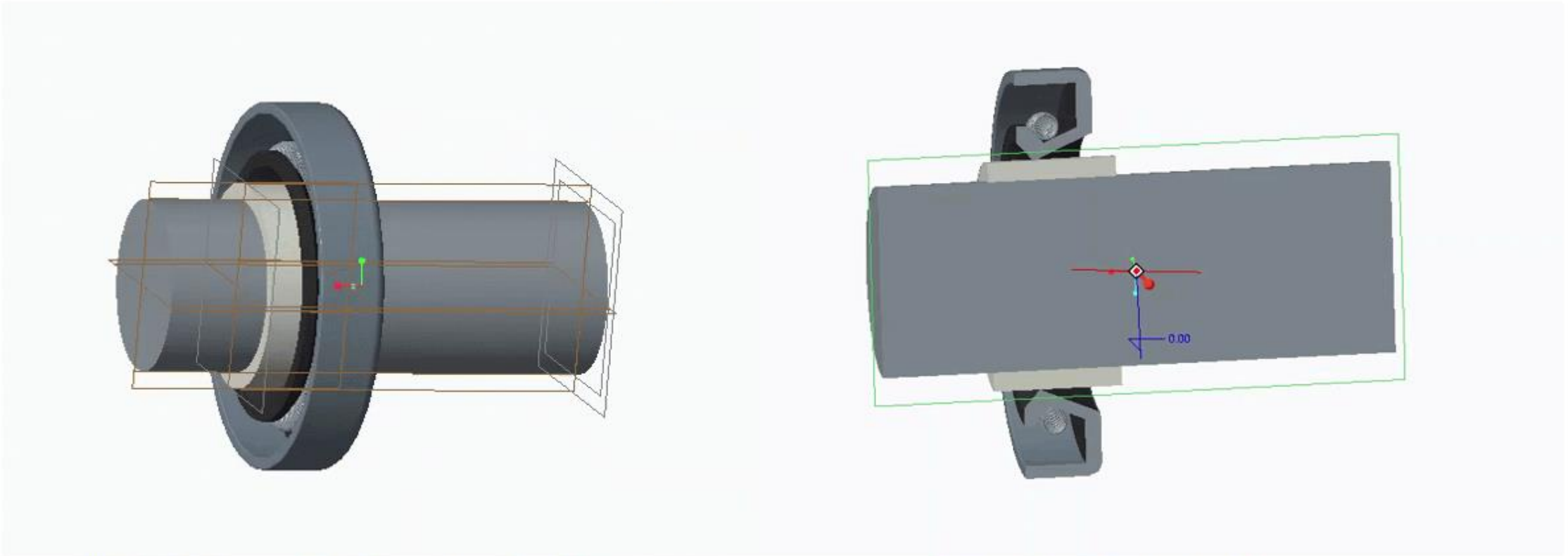
Radial Lip Seals for Aerospace Applications: an overview

Sarah Shabbir
Supervisors: Seamus D. Garvey, Sam M. Dakka, Benjamin C. Rothwell

Institute of Aerospace Technology
Gas Turbine and Transmission Research Centre
University of Nottingham

Section View & Seal-Shaft

Pre-loaded with a Garter Spring Design mounted on a Elastomeric Radial Lip Seals sleeve, that is fixed to the shaft



*This 3D image has been downloaded from an open-source website GRABCAD for demonstration purposes. There is no dust lip in this seal design, but several elastomeric seals include a dust lip.

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Overview of PhD Research

Ansys & SOLIDWORKS

Modelling

- Modelling of radial lip seals to understand underlying fluid mechanics of sealing mechanisms

Experimental Test Bench

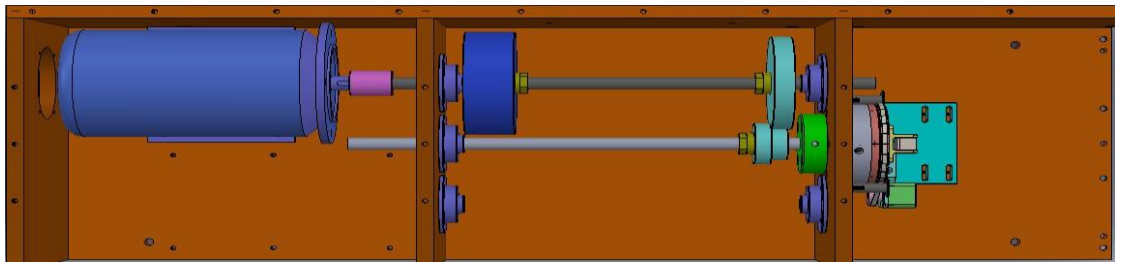
Experimental

- Seal, shaft, and lubricant interaction i.e., sealing interface
- Identify optimum parameters
  - Shaft: lead, hardness, coating, surface roughness
  - Seal: polymer selection, hardness, surface roughness, filler content
  - Lubricant: viscosity, compatibility

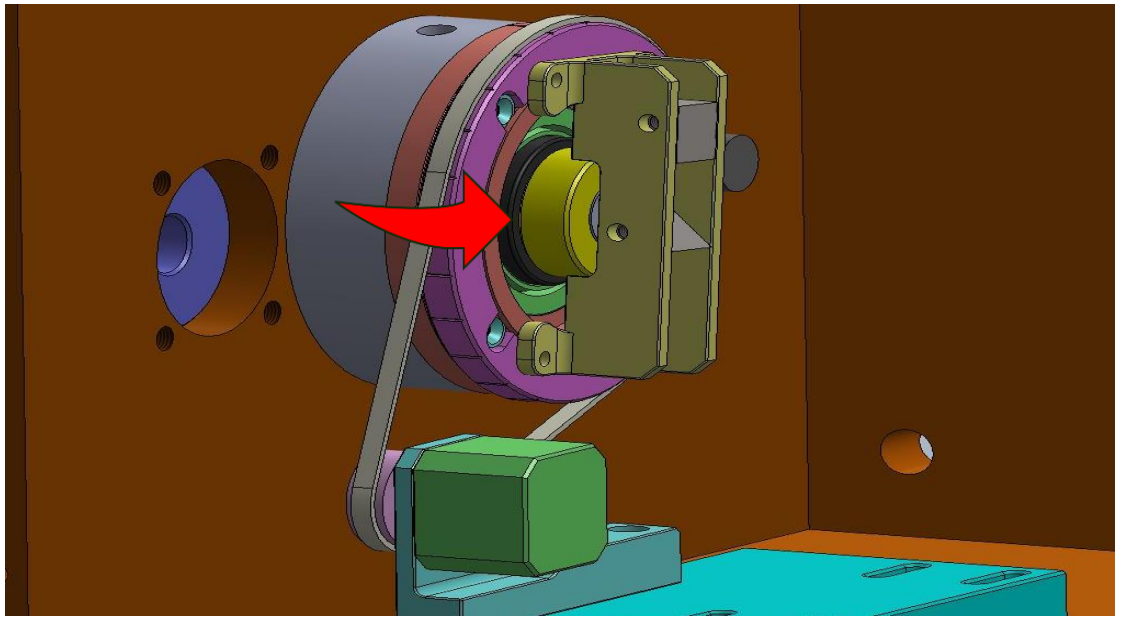
Project Focus

Elastomeric radial lip seals are placed in the input and output locations of **helicopter gearboxes** to prevent loss of oil out of the system

Transmission



Power Source **Seal Test Bench**



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Shaft/Sleeve Surface

All standards mentioned are only relevant to elastomeric radial lip oil seals.
Requirements of a successful sealing system are defined by discussing the standards that reference these specifications.

1. Lead/Texture
2. Surface Roughness
3. Vickers Hardness

All Determined By

Coatings	Surface Finish Method

	DIN* 3760	ISO** 6194-1	RMA*** OS-1-1
Shaft lead	Zero lead angle, 0°	Zero lead angle, 0°	0±0.05°.
Shaft surface roughness	Ra 0.2 µm to 0.8 µm	Ra 0.2 µm to 0.5 µm	Ra 0.2 µm to 0.43 µm
Hardness	>45 HRC	>30 HRC, >45 HRC if subject to damage	>30 HRC, >45 HRC if subject to damage

*DIN = Deutsches Institut für Normung
**ISO = International Organization for Standardization
***RMA = Rubber Manufacturers Association

Lead	Shaft Rotation	Transport Direction
RH	CW	Right/ Free end/ leakage
RH	CCW	Left/ Fixed end/ reverse
LH	CW	Left/ Fixed end/ reverse
LH	CCW	Right/ Free end/ leakage

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Seal

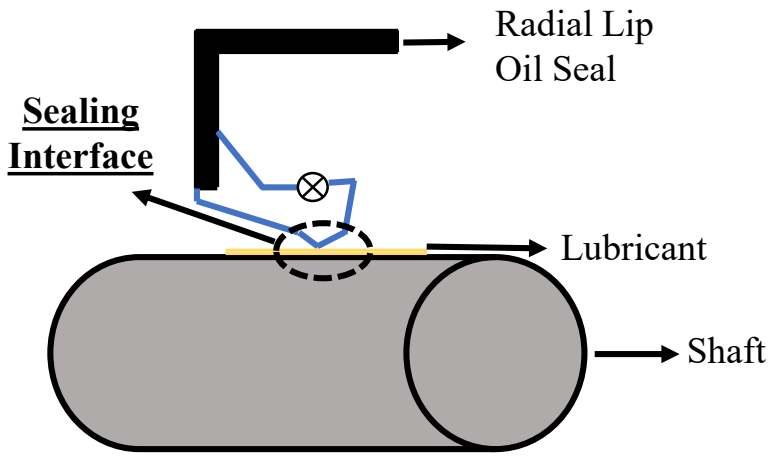
1. Seal Material Elastomer selection
2. Filler Content & Composition
3. Hardness (Shore A & D)
4. Lip Coating
5. Garter Spring
6. Surface Roughness
7. Housing Bore
8. Tolerances

	Standards	Notes
Seal Materials	Elastomer classification - ASTM D 1418	M types (E.g. FKM, EPDM) or R types (NBR), etc…
Reinforcing Fillers	Freudenburg Sealing Solutions	Carbon black, silica based fillers, calcium carbonate
Hardness	-	Shore A & D hardness determined by elastomer selection
Lip Coating	-	Sometimes, PTFE-lined seals are used for better tribological properties at interface
Garter Spring	Materials – DIN 17223, DIN 1.4300/1.4301 (corrosion)	Does not age with elastomer, provides constant & stable force throughout use
Surface Roughness	-	Bedding in process of seal by sliding against shaft
Housing Bore	Tolerance - DIN 3761 – ISO H8 Surface roughness – DIN 3760	A good fit of the shaft seal into the housing bore is necessary
Tolerances	Seal dimensions - ISO 6194-1, DIN 3761, RMA OS-4	Tolerances provided for metric and inch size seals

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Lubricant

The sealing lip does not actually run on the shaft directly, but on an oil film called meniscus, 1 - 3 [μm] in thickness.



Meniscus is influenced by:

1. **Viscosity of oil**
2. **Shaft surface finish**
3. **Seal Radial Load**

The purpose of lubrication is:

1. **Reduce friction**
2. **Reduce wear**
3. **Act as coolant – dissipate heat generated**

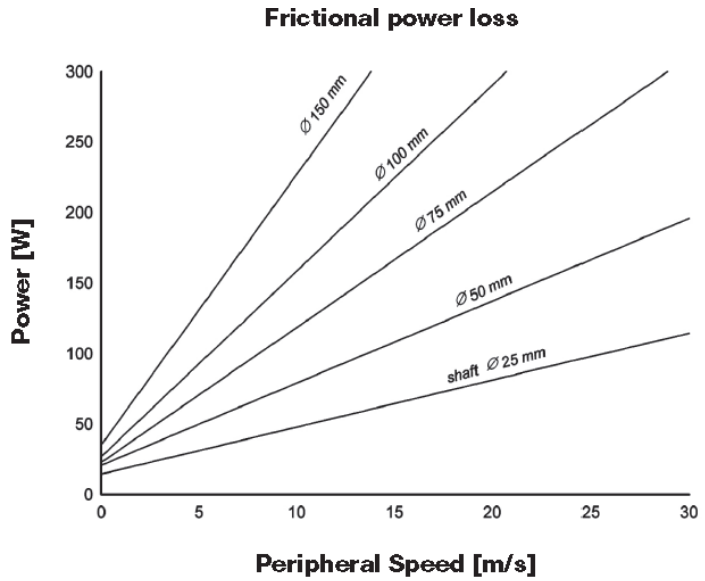
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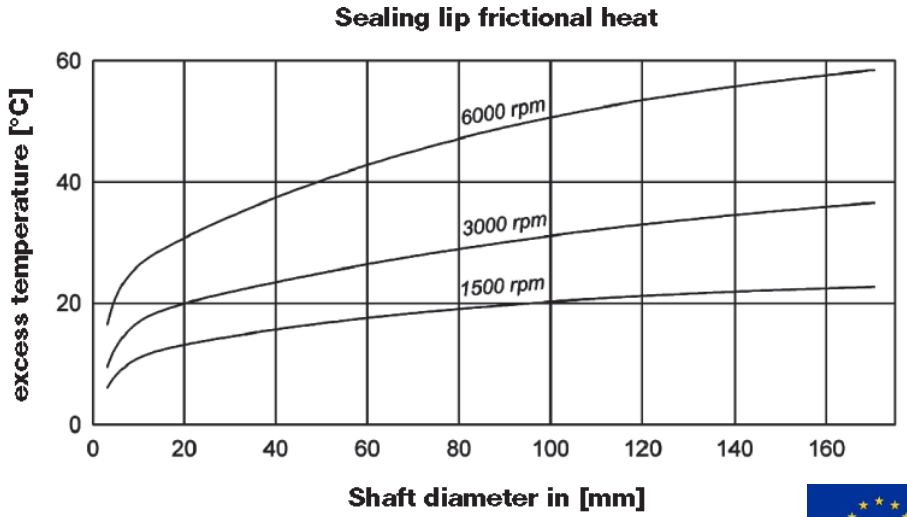
Operating Conditions

1. Rotational Speeds
2. Frictional Power Loss
3. Temperatures/ Temperature Resistance
4. Pressures
5. Leakage* Control

	Standards
Rotational Speeds	DIN 3760/1
Frictional Power Loss	SKF, Trelleborg, Dichta (credit for graph)
Temperatures	Trelleborg, Dichta (credit for graph)
Pressures	Trelleborg, Dichta

*Leakage refers to oil/lubricant escaping past the elastomeric seal





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Leakage Control – DIN 3761

1. Leakage control for systems:
   - static sealing (two surfaces with no relative motion)
   - dynamic sealing (two surfaces with relative motion).
2. Rotating shaft
   - Sliding surfaces separated by a fluid film
     - a dynamic seal gap forms.
3. Dynamic seal gap prevents absolute tightness when moving parts are involved (dynamic seals)
4. Technical tightness: leakage reduction until no negative environmental or operational consequences (user/application defined).

	DIN 3761
Technical tightness of lip-seals	Classification 1-3
Zero leakage	Moisture film at sealing edge still present. Also called 'minimum leakage' functionally
Permissible amount for motor vehicles	1g to 3g per seal for test time of 240 hrs

- Oil leakage will result in oil stains along the side of the helicopter, and debris entering into the gearbox will reduce component life.

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Challenges with Seals



Airbus A320neo – 2017-2018

- (Trimble, 2018; Bogaisky, 2018)

Airbus A330-323 – 2016

- (AAIB Field Investigation, 2017)

Airbus A320 – 2014

- (AAIB Field Investigation, 2014)

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Conclusions

Note that my experimental and numerical analysis experience is limited to elastomeric radial lip oil seals.

1. All seals will leak to some extent, even if it is minimal and referred to as 'emission' rather than a leak[1].

2. Such (elastomeric radial lip) dynamic oil seals cannot achieve absolute tightness.
   Only technical tightness can be achieved.
   Technical tightness is a loose term.

3. A perfect sealing system* does not exist.
   Leakage control must be defined by the user/application for each oil seal.
   Achieving higher leakage control might mean compromising on degree of wear.

4. The requirements for elastomeric radial lip oil seals, their mating surfaces (shafts) and lubricant are very specifically defined and are critical in achieving a successful seal.

[1] Flitney, R. K. (2014). A description of the types of high speed rotary shaft seals in gas turbine engines and the implications for cabin air quality Journal of Biological Physics and Chemistry, 14(4), 85–89

*Sealing system has been defined earlier. In the 1980's, the concept of a 'sealing system' replaced the concept of just a single seal commodity, a critical point in radial lip seal evolution. This also refers to the seal-mating surface (shaft or sleeve) in combination with the seal and lubricant.

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THANK YOU

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Editors: Dieter Scholz, Susan Michaelis

AIRCRAFT CABIN AIR
International Conference 2021

Chronic Low Level Exposure to Organophosphates

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E-Mail: aterry@augusta.edu

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Abstract

Purpose: The purpose of the work reviewed in this abstract was to evaluate potential treatment strategies against the negative effects of the highly toxic class of chemicals, the organophosphates (OPs), on a fundamental process in neurons, axonal transport (AXT).

Methodology: Using a time-lapse imaging technique, we evaluated OP effects on fast AXT of fluorescent membrane-bound organelles in cultured primary cortical neurons from rats. We also developed a manganese-enhanced magnetic resonance imaging (MEMRI) method for real-time measurements of AXT rates in mice in the olfactory system over a single scanning session. Both methods were used to evaluate therapeutic strategies designed to enhance AXT rates.

Findings: Our previous neuronal culture and animal experiments indicated that exposures to OPs of different classes (e.g., insecticide and nerve agent) can lead to impairments of AXT, a potential mechanism of the long-term neurological impairments observed in humans exposed to OPs. Subsequent in vitro phenotypic screening studies indicated that some currently prescribed drugs (lithium chloride, methylene blue) with multi-target pharmacological activity could have potential as repurposed drugs for OP-related neurological impairments as a result of their ability to attenuate the deleterious effects of OPs on AXT. We have also developed an MEMRI method where real-time measurements of AXT rates can be determined in living mice in the olfactory system over a single scanning session. Using this method, we determined that AXT rates were slower in aged vs young mice. In aged mice, the microtubule stabilizing compound Epothilone D was associated with significant improvements in AXT rates. The conclusion of these studies was that our new MEMRI method is sensitive to the negative effects of aging on AXT as well as microtubule-focused therapeutic strategies for improving AXT. Future studies will focus on OP effects/therapeutic strategies using this method.

Research Limitations: All of the studies described in this report were conducted in vitro or in animal models.

Practical Implications: Our studies further suggest that impairments of AXT may underlie the long term deleterious neurologic effects that have been associated with OPs. Moreover, we have identified compounds that could potentially be used to attenuate the negative effects of OPs on AXT.

Value and Originality: The value of the methodology we have developed for assessing the effects OPs on AXT lies in its potential for elucidating novel therapeutic targets and treatment strategies against OP toxicity. The results could have therapeutic implications for conditions that have been associated with repeated OP exposures, such as Gulf War Illness and Aerotoxic Syndrome.

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Related presentation: https://doi.org/10.5281/zenodo.4730434
Review process: Editorial review. The corresponding author is marked with *.

Keywords

pesticide, nerve agent, Gulf War illness, aerotoxic syndrome, axonal transport, therapeutic strategies

1 Introduction

The chemicals known as the organophosphates (OPs) are found in hundreds of products used worldwide including pesticides, defoliants, fire retardants, industrial solvents, lubricants, plasticizers, and fuel additives (Soltaninejad and Shadnia, 2014; Costa 2018). Many OPs can be highly toxic and associated with acute symptoms (also known as the cholinergic crisis) which include excessive secretions, cardiorespiratory depression, and seizures, which can be life threatening (reviewed, Pereira et al., 2014). These acute symptoms can also lead to a variety of long-term neurological and psychiatric consequences in survivors. In contrast to acute OP poisoning, the long-term consequences of repeated exposures to levels of OPs below the threshold for acute "cholinergic" toxicity are less clear and controversial, but long-term neurological and psychiatric consequences have also been associated with this type of exposure as well as chronic conditions such as Gulf War Illness and Aerotoxic Syndrome (reviewed Naughton and Terry, 2018). While there are antidotal regimens available to treat the symptoms of acute OP toxicity, there are no established treatments for the long-term neurological consequences of OP exposure. It is now well recognized that OPs, in addition to inhibiting the cholinergic acetylcholinesterase (AChE), can negatively affect multiple protein targets as well as biological processes. Studies in our laboratory over the past 20 years using both in vitro and in vivo models indicate that relatively low level exposures to some OPs can lead to impairments in axonal transport (AXT). Given the fundamental nature of AXT to neuronal health, we rationalized that this process might serve as a general focus area for novel therapeutic strategies against OP toxicity. In the first series of published studies reviewed in this Abstract (see Naughton et al., 2020), we employed a multi-target, phenotypic screening, and drug repurposing strategy for the evaluations of potential novel OP-treatments using a primary neuronal culture model and time-lapse live imaging microscopy. In the second series of (unpublished) studies reviewed in this Abstract, we developed a manganese-enhanced magnetic resonance imaging (MEMRI) method where real-time measurements of AXT rates can be determined in living mice in the olfactory system over a single scanning session. Using this method, we evaluated the effects of aging on that AXT rates in mice and subsequently evaluated a potential therapeutic strategy designed to enhance AXT rates.

2 Methods

2.1 In Vitro Studies

Using a time-lapse live cell imaging technique, we evaluated OP effects on fast AXT of membrane bound organelles (MBOs) in rat primary cortical neurons that contained the amyloid precursor protein (APP) tagged with the fluorescent marker GFP. Subsequently, two multi-target compounds, lithium chloride (LiCl) and methylene blue (MB), which are FDA-approved for other indications (Bipolar Disorder and methhemeglobinemia, respectively), were evaluated for their ability to prevent the negative effects of the OP, diisopropylfluorophosphate (DFP) on axonal transport.

2.2 In Vivo Studies

A noninvasive MEMRI method was developed for measuring AXT in living mice in real time in olfactory receptor neurons, which project from the olfactory epithelium to the olfactory neuronal layer (ONL) of the olfactory bulb. Using this new MEMRI method, two major experiments were conducted: 1) an evaluation of the effects of age on AXT in wild-type mice and 2) an evaluation of the effects of microtubule stabilizing compound Epothilone D on axonal transport in aged, wild-type mice.

3 Results

3.1 In Vitro Studies

In these studies, we replicated previous work where the OP, DFP was found to impair AXT in a concentration-dependent manner. The results also indicated that both LiCl and MB prevented DFP-induced impairments in anterograde and retrograde AXT velocities in a concentration dependent manner.

3.2 In Vivo Studies

In these studies, we improved upon previous MEMRI approaches to develop a method where real-time measurements (32 time points) of AXT rates in mice can be determined over a single scanning period. The new MEMRI method is sensitive to the negative effects of aging on AXT in wild type mice. The brain-penetrant, microtubule stabilizing compound Epothilone D administered once per week for eight weeks was associated with significantly increased rates of AXT in aged mice.

4 Summary and Conclusions

Our previous animal and neuronal culture experiments indicated that exposures to OPs of different classes (e.g., insecticide & nerve agent) can lead to impairments of AXT, a potential mechanism of the long-term neurological impairments observed in humans exposed to OPs. Our recently published in vitro phenotypic screening studies indicated that some currently prescribed drugs (LiCl, MB) with multi-target pharmacological activity could have potential as repurposed drugs for OP-related neurological impairments as a result of their ability to attenuate the deleterious effects of OPs on AXT. While in vivo studies will be required to confirm our in vitro findings, these experiments support the potential of LiCl and MB as repurposed drugs for the treatment of the long-term neurological deficits associated with OP exposure (currently an unmet medical need). In more recent (unpublished) experiments we developed an improved (noninvasive) MEMRI method where real-time measurements of AXT rates can be determined in vivo (mice) in the olfactory system over a single scanning session. Using this method, we determined that AXT rates were clearly slower in aged vs young mice. In aged mice, the brain-penetrant microtubule stabilizing compound Epothilone D was associated with statistically significant improvements in AXT rates. The conclusion of these studies was that our new MEMRI method is sensitive to the negative effects of aging on AXT as well as microtubule-focused therapeutic strategies for improving AXT. Future studies will focus on OP effects/therapeutic strategies using this method which could have therapeutic implications for conditions that have been associated with repeated OP exposures, such as Gulf War Illness and Aerotoxic Syndrome.

Acknowledgements

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Chronic Low Level Exposure to Organophosphates

International Aircraft Cabin Air (Virtual) Conference, March 17, 2021.

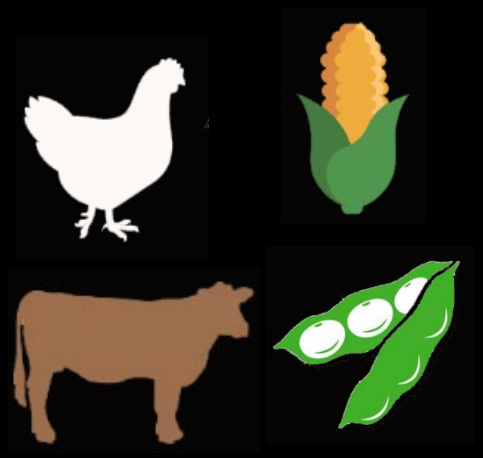
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Alvin V. Terry Jr., Ph.D.
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Chronic Low Level Exposure to Organophosphates

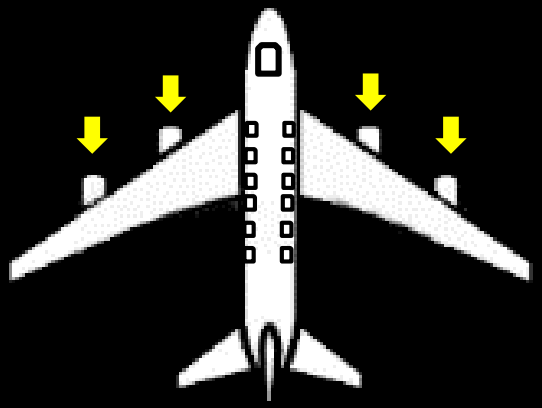
Alvin V. Terry, Jr., Ph.D.



OP Exposures

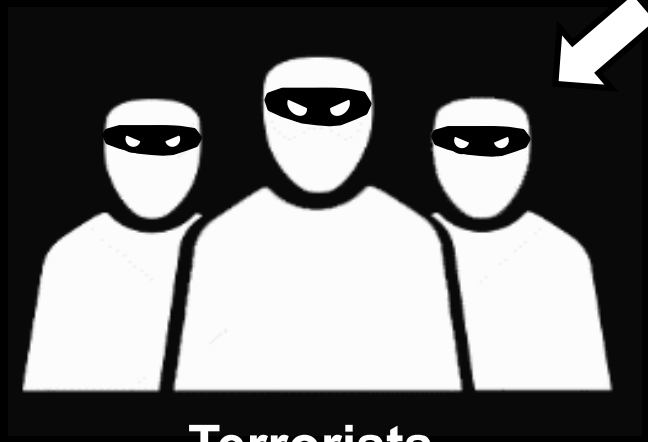


Agricultural Exposures



Fume Events

$$R_1\text{-}O\text{-}P(=O)\text{-}O\text{-}R_2$$

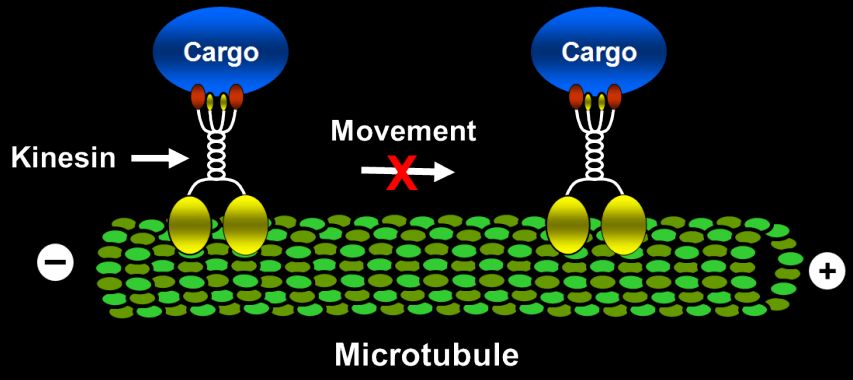


Terrorists And Rogue Governments

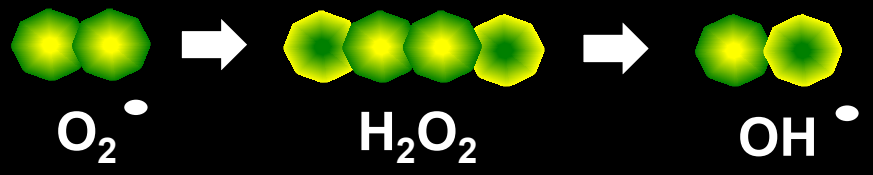


Other Environmental Exposures

Reviewed, Naughton and Terry, *Toxicology* 408: 101–112, 2018



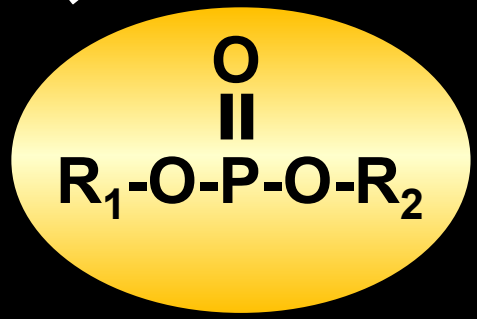
Axonal Transport Deficits



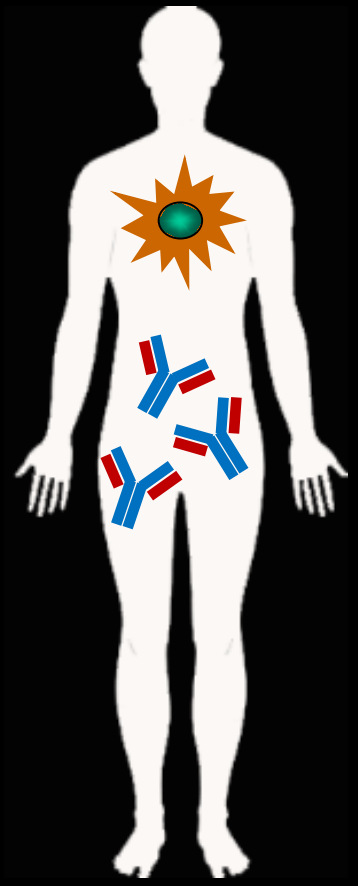
Oxidative Damage



Neuroinflammation

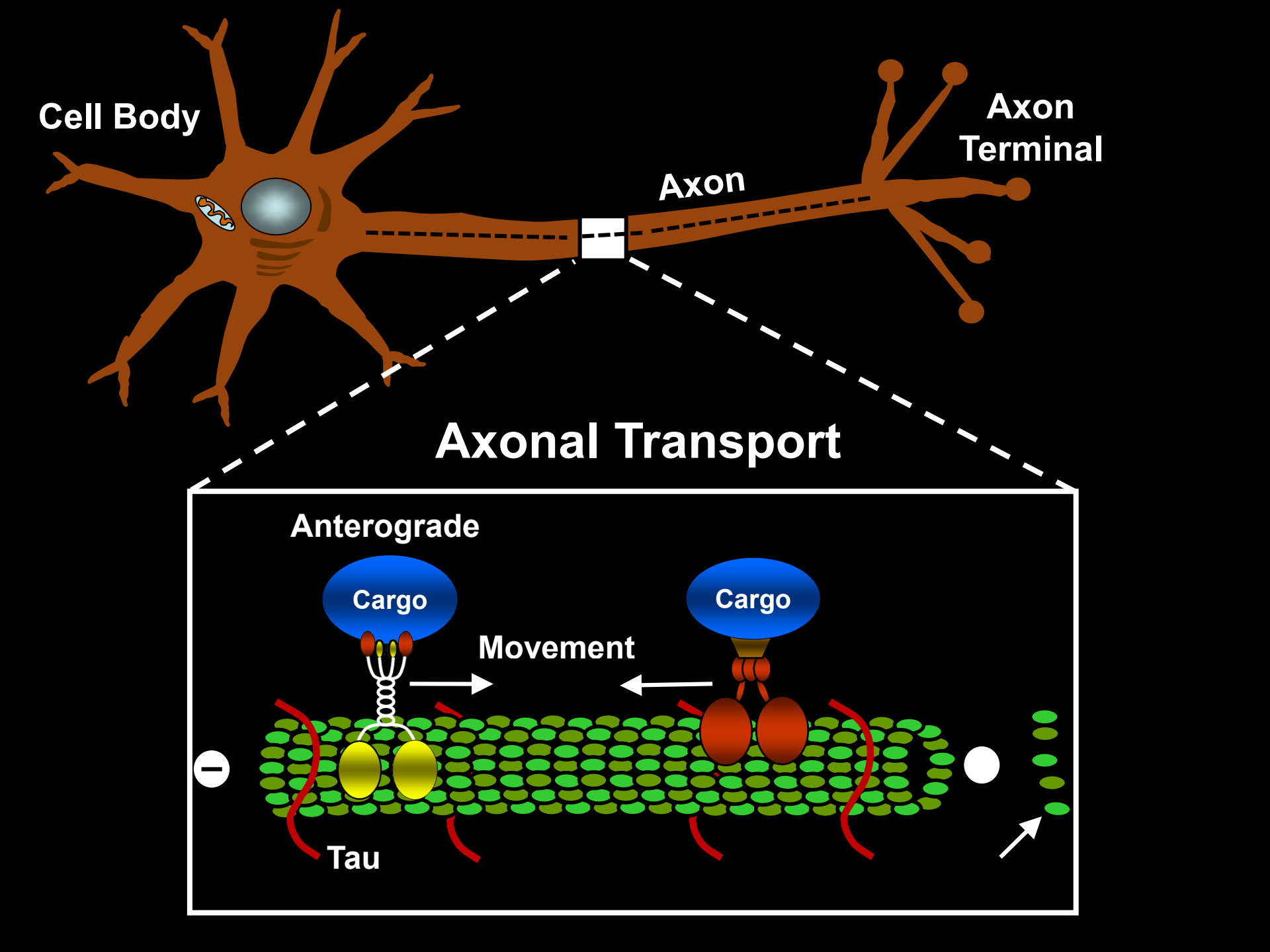


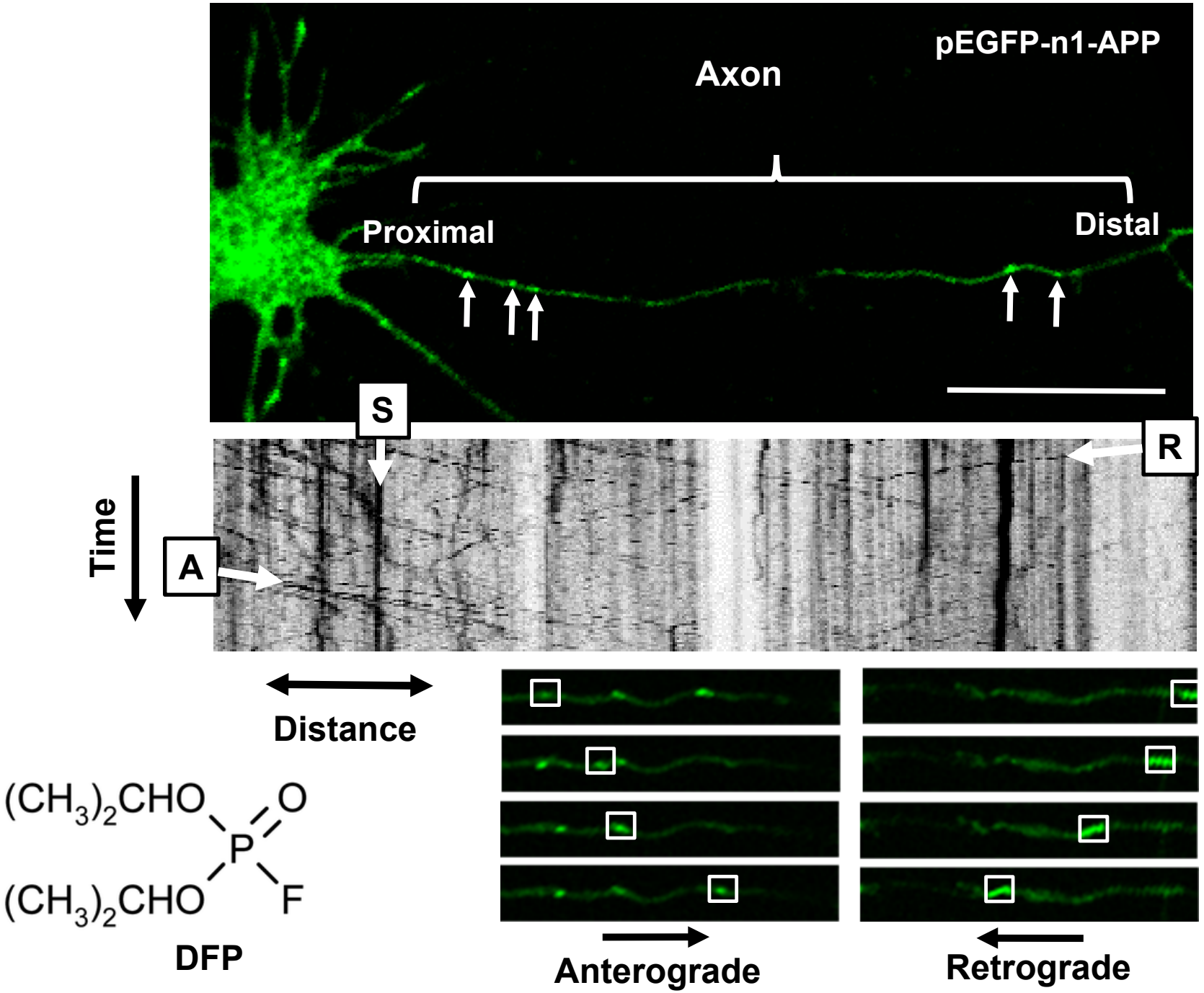
OPs- Potential Long-Term Effects



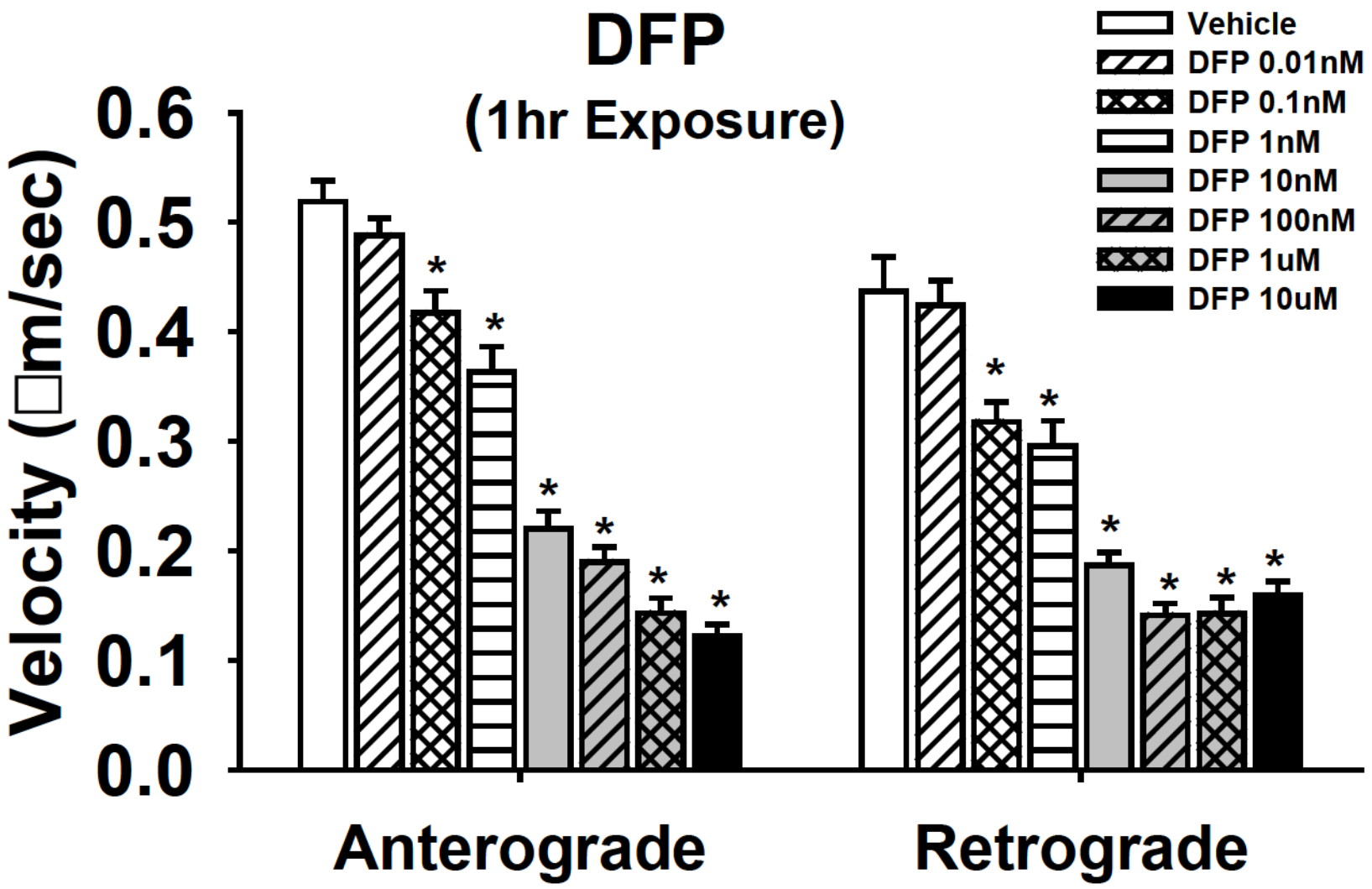
Autoimmunity

Reviewed, Naughton and Terry, *Toxicology* 408: 101–112, 2018


Cell Body
Axon
Axon Terminal
Axonal Transport
Anterograde
Cargo
Cargo
Movement
Tau


pEGFP-n1-APP
Axon
Proximal
Distal
S
R
A
Time
Distance
$(CH_3)_2CHO$
O
P
$(CH_3)_2CHO$
F
DFP
Anterograde
Retrograde

In Vitro Axonal Transport Studies



* p< 0.05 versus vehicle control velocity

Gao et al., *J Pharmacol Exp Ther* 356:645–6558, 2016

1521-0103/356/3/645–655$25.00
THE JOURNAL OF PHARMACOLOGY AND EXPERIMENTAL THERAPEUTICS
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http://dx.doi.org/10.1124/jpet.115.230839
J Pharmacol Exp Ther 356:645–655, March 2016

Diisopropylfluorophosphate Impairs the Transport of Membrane-Bound Organelles in Rat Cortical Axons[S]

Jie Gao, Sean X. Naughton, Heike Wulff, Vikrant Singh, Wayne D. Beck, Jordi Magrane, Bobby Thomas, Navneet Ammal Kaidery, Caterina M. Hernandez, and Alvin V. Terry, Jr.

Department of Pharmacology and Toxicology, Georgia Regents University, Augusta, Georgia (J.G., V.S., S.X.N., W.D.B., B.T., N.A.K., C.M.H., A.V.T.); Department of Pharmacology, University of California–Davis, Davis, California (H.W.); Feil Family Brain and Mind Research Institute, Weill Cornell Medicine, New York, New York (J.M.)

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NeuroToxicology 62 (2017) 111–123

Contents lists available at ScienceDirect

NeuroToxicology

Full length article

Chlorpyrifos and chlorpyrifos oxon impair the transport of membrane bound organelles in rat cortical axons☆

Jie Gao[a], Sean X. Naughton[a], Wayne D. Beck[a], Caterina M. Hernandez[a], Guangyu Wu[a], Zhe Wei[a], Xiangkun Yang[b], Michael G. Bartlett[b], Alvin V. Terry Jr.[a,*]

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Toxicology 431 (2020) 152379

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Toxicology

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Multifunctional compounds lithium chloride and methylene Blue attenuate the negative effects of diisopropylfluorophosphate on axonal transport in rat cortical neurons

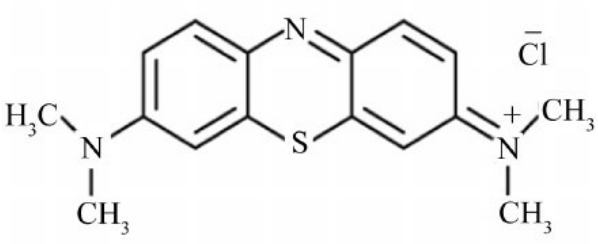
Sean X Naughton, Wayne D. Beck, Zhe Wei, Guangyu Wu, Alvin V. Terry Jr*

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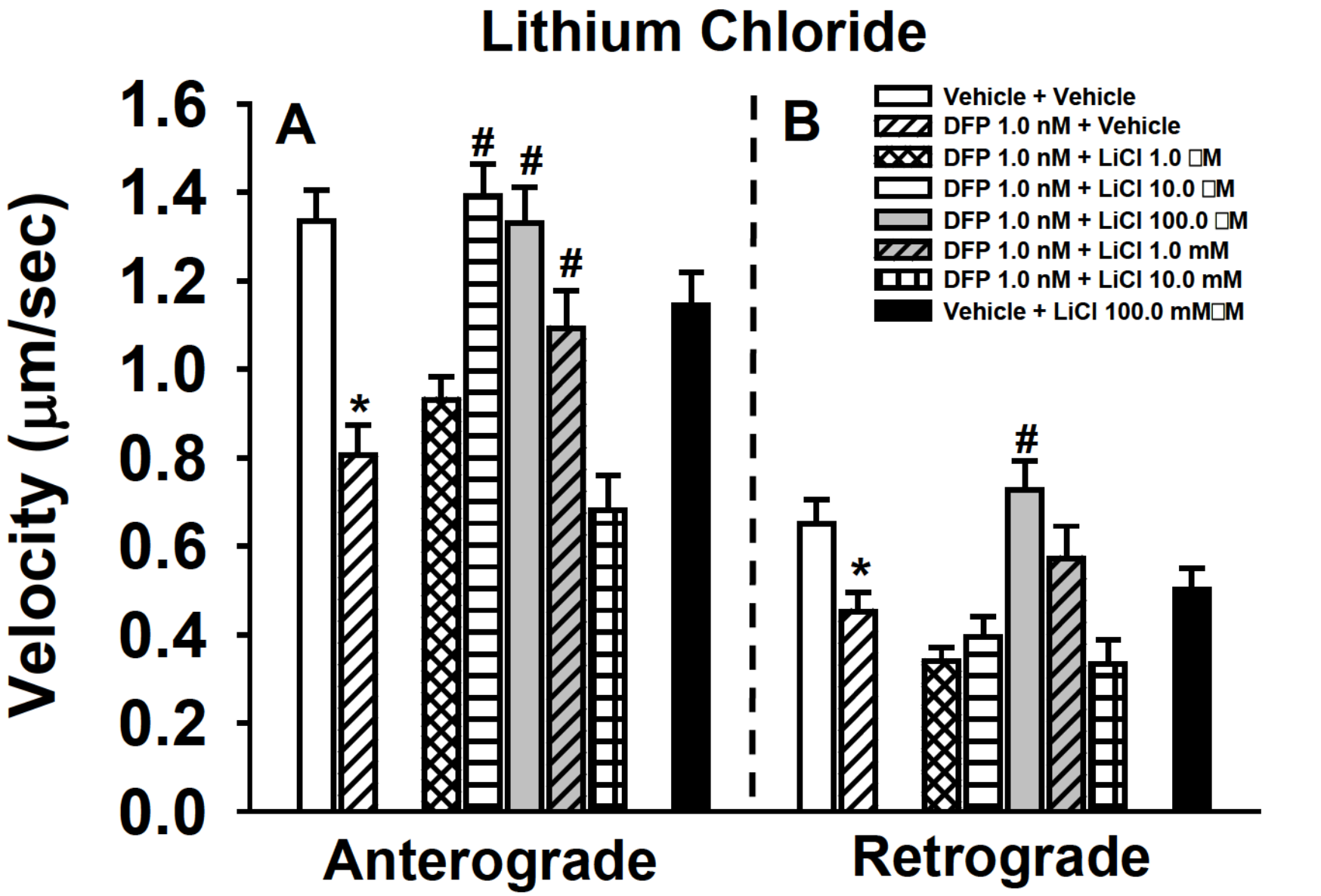
LiCl





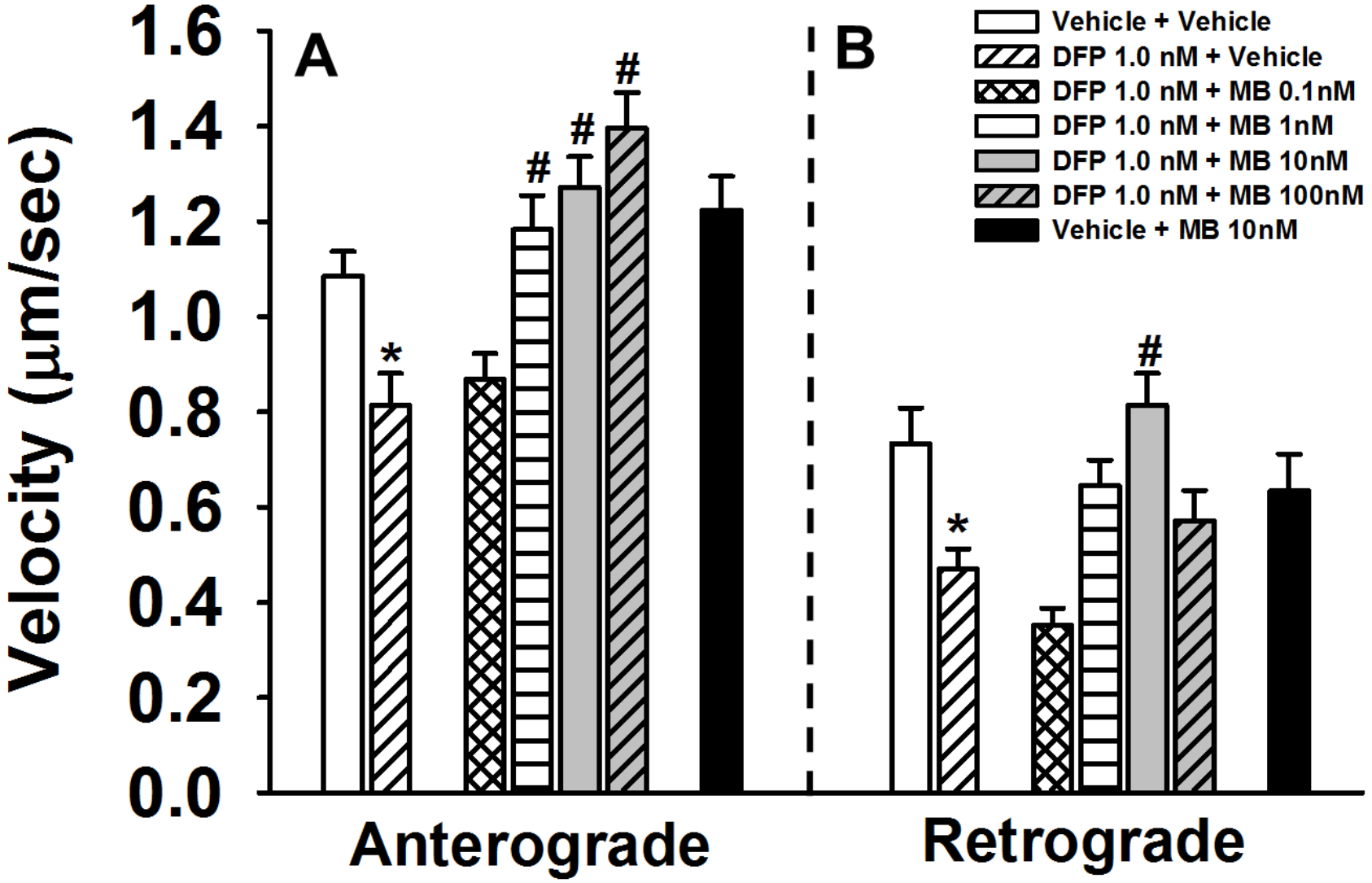
Methylene Blue

"Multi-target, phenotypic screening, and drug repurposing strategy"



Naughton et al., *Toxicology* 2020

Methylene Blue



Naughton et al., *Toxicology* 2020

NeuroToxicology 47 (2015) 17–26

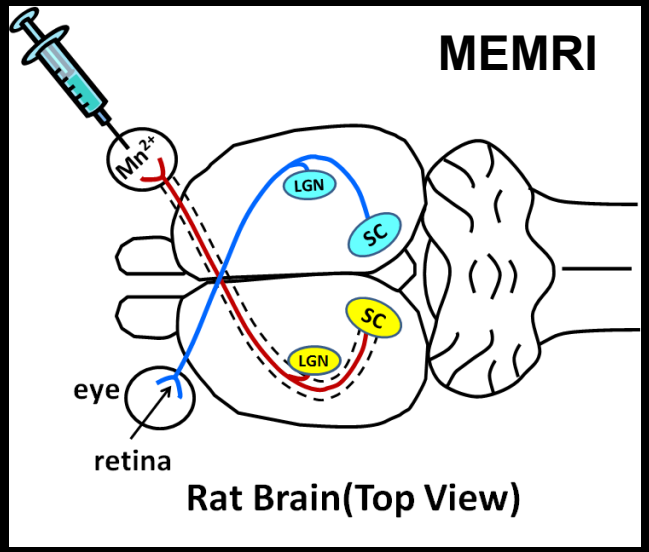
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NeuroToxicology

Repeated exposure to chlorpyrifos leads to prolonged impairments of axonal transport in the living rodent brain

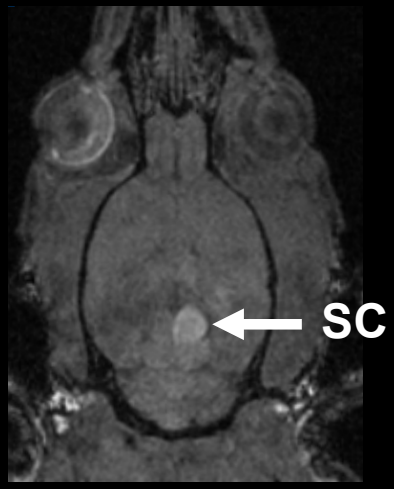
Caterina M. Hernandez [a], Wayne D. Beck [a], Sean X. Naughton [a], Indrani Poddar [a], Bao-Ling Adam [a], Nathan Yanasak [b], Chris Middleton [b], Alvin V. Terry Jr [a,*]

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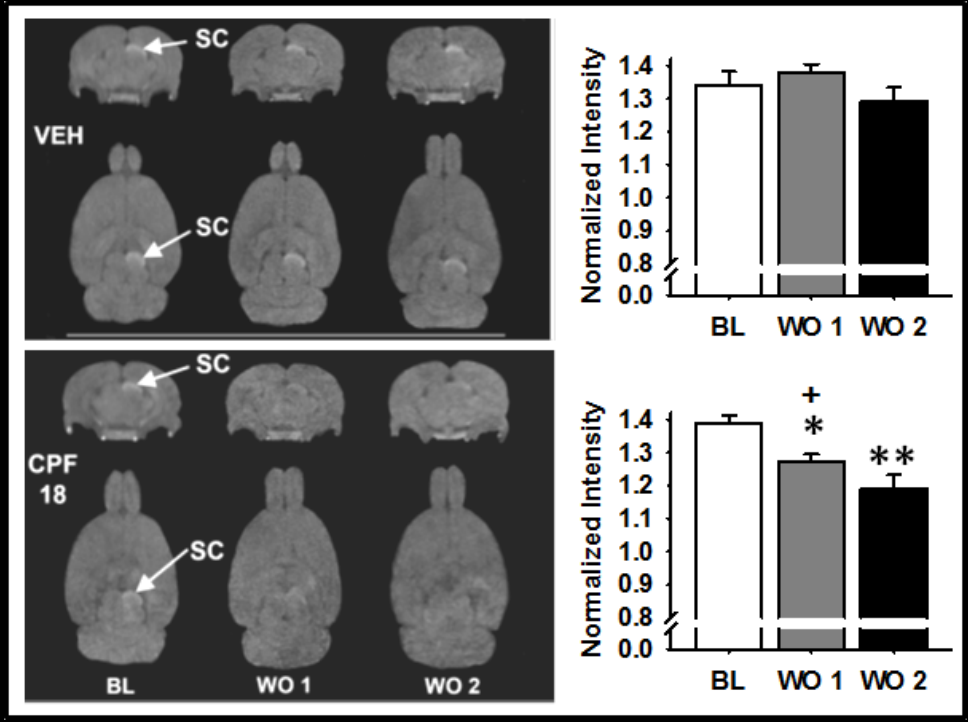




6 hrs



24 hrs



Chlorpyrifos (CPF) Study

Toxicology 406–407 (2018) 92–103

Contents lists available at ScienceDirect

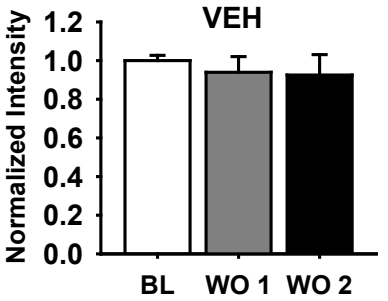
Toxicology

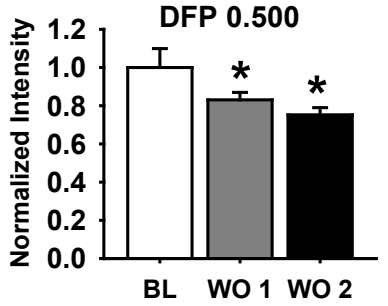
journal homepage: www.elsevier.com/locate/toxicol

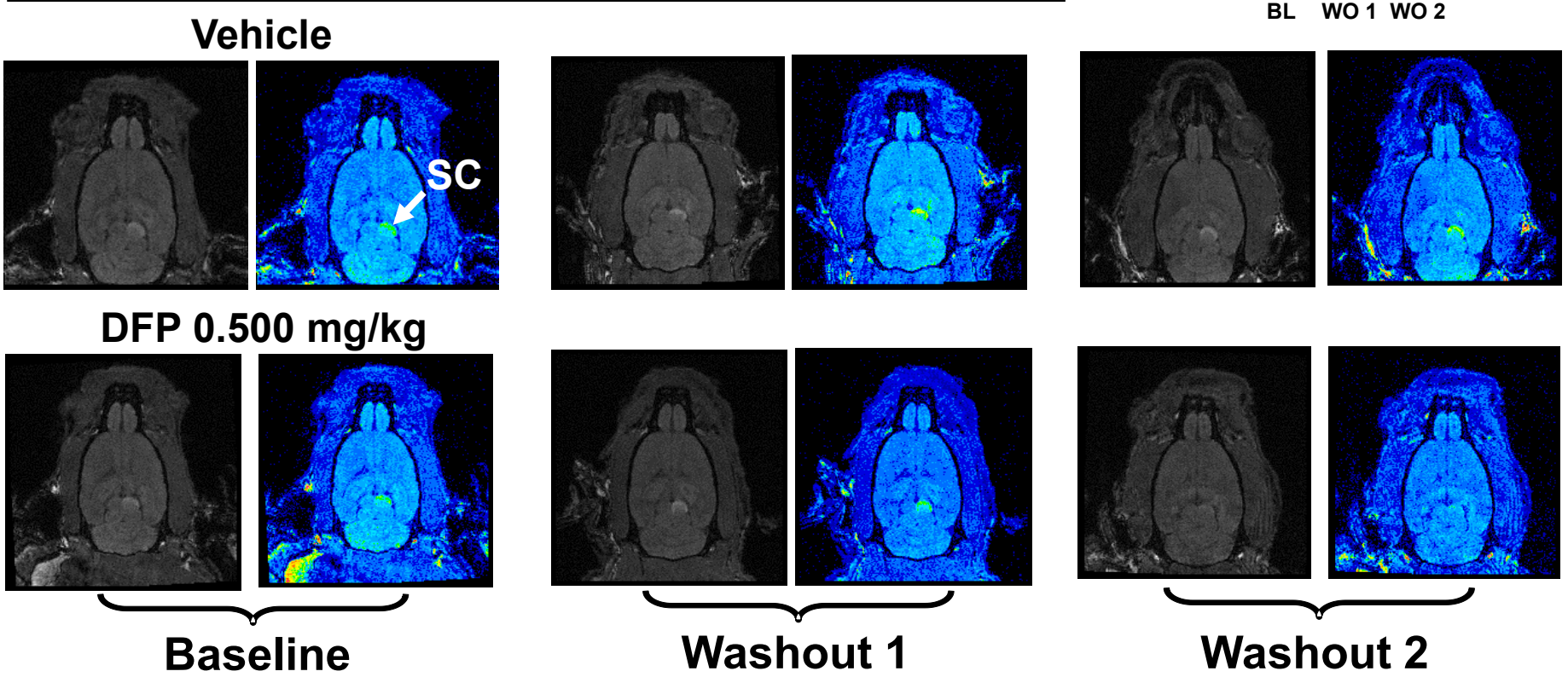
Repeated exposures to diisopropylfluorophosphate result in structural disruptions of myelinated axons and persistent impairments of axonal transport in the brains of rats

Sean X. Naughton[a], Caterina M. Hernandez[a], Wayne D. Beck[a], Indrani Poddar[a], Nathan Yanasak[b], Ping-Chang Lin[b], Alvin V. Terry Jr.[a,*]

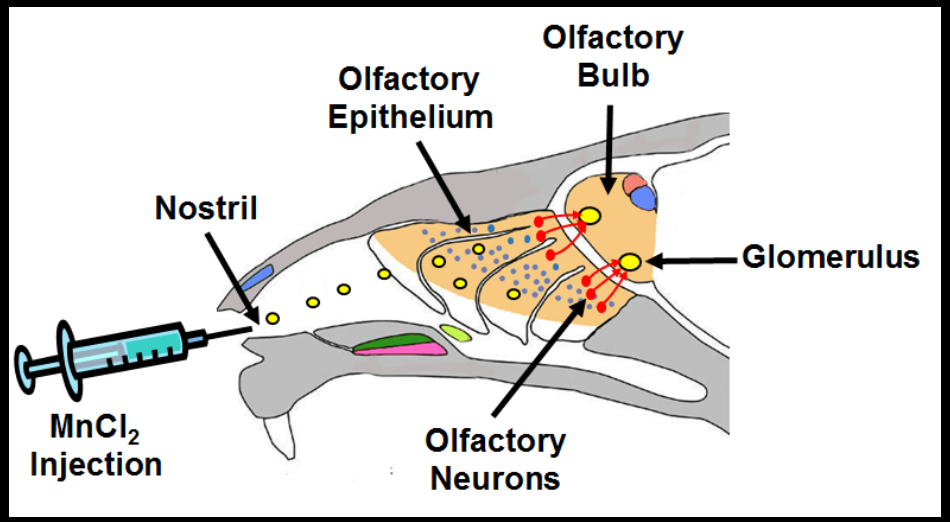
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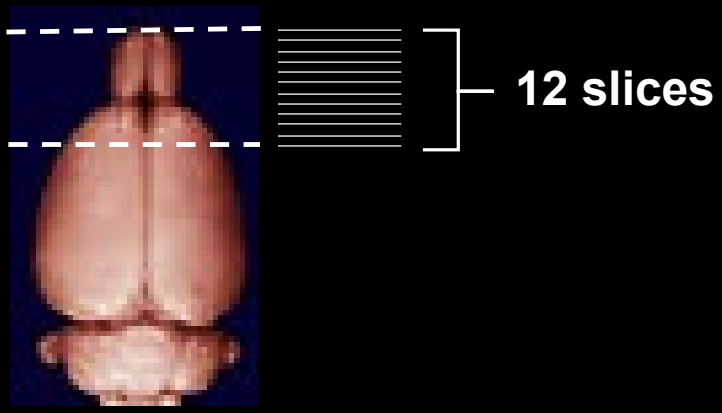






$MnCl_2$ Administration & MRI Scanning Protocol





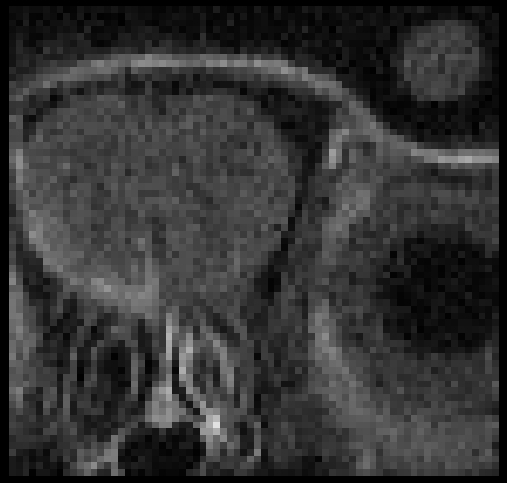
- Mouse is anesthetized (isoflurane).
- $MnCl_2$ (3.3 μM) solution is administered unilaterally to one nostril.
- Subject is allowed to regain consciousness and is monitored for signs of distress.
- Mouse is re-anesthetized and placed in a prone position on an MR-compatible cradle.

- T1W MRI Scans were obtained focused on the olfactory bulb.
- Scans covered an anatomical range of 2 sections prior to emergence of the OB through 2 sections after the optic chiasm.
- 12 sections @ 0.75 mm thick each were repeatedly scanned.
- 32 time points (scan duration ~100 min) were obtained.

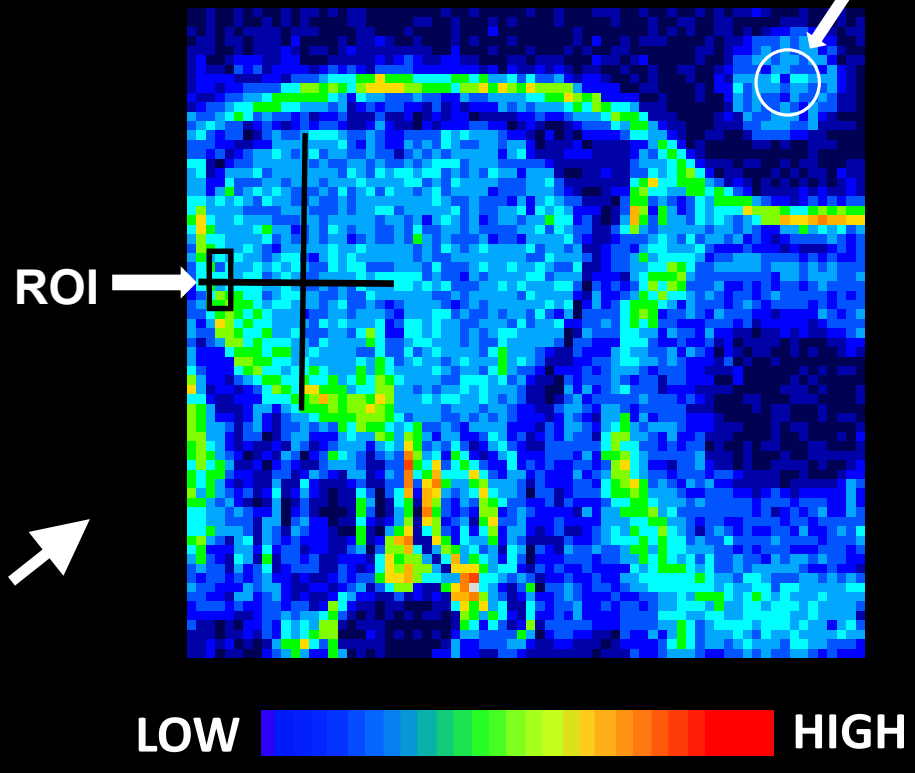
MEMRI Analysis Method



Whole Head Scan



Cropped Image



Color-Enhanced Image

ROI of the ONL = 2 x 4 pixels
ROI of the saline-filled phantom (BG) diameter = 5 pixels

MEMRI: Age Comparison

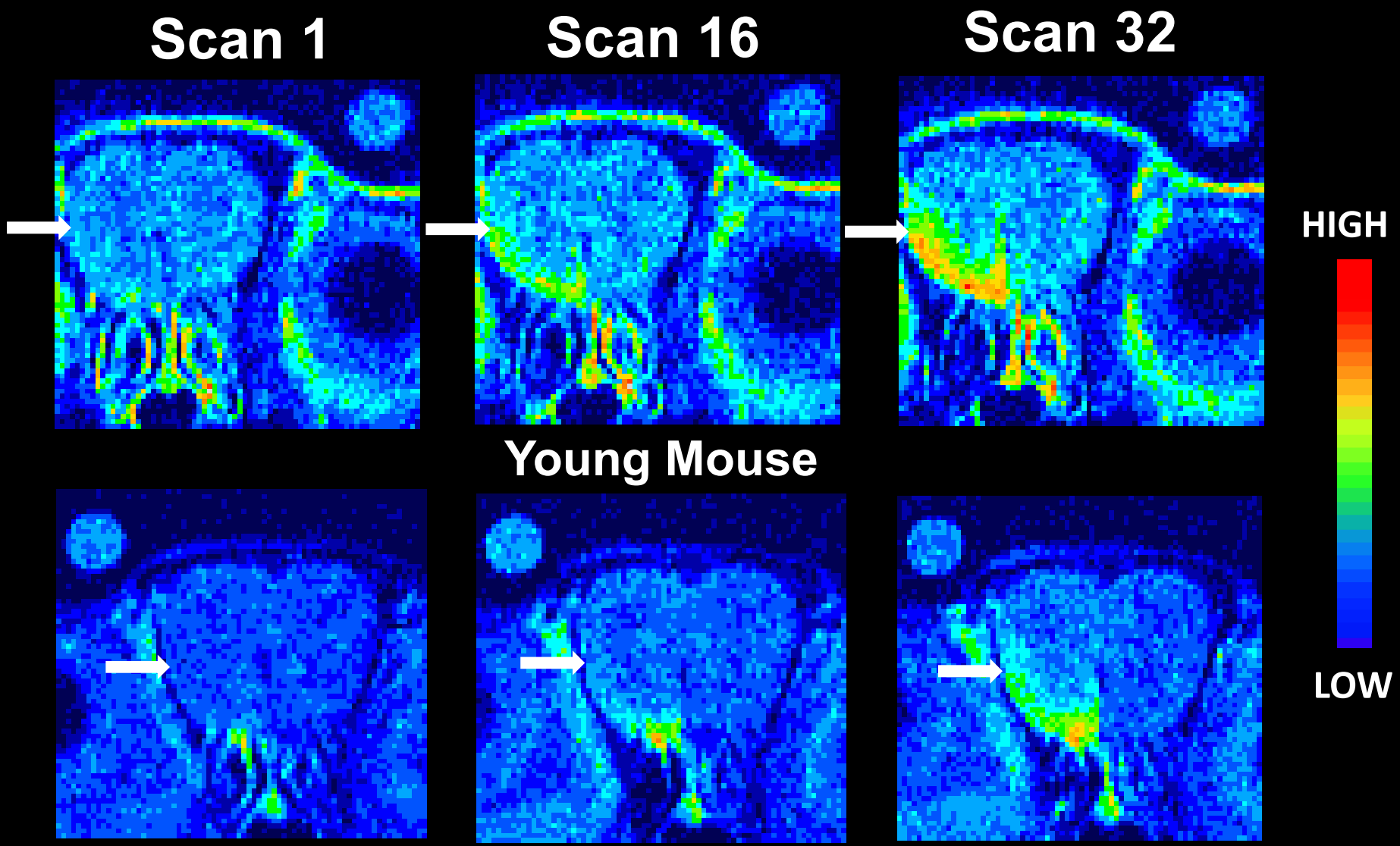
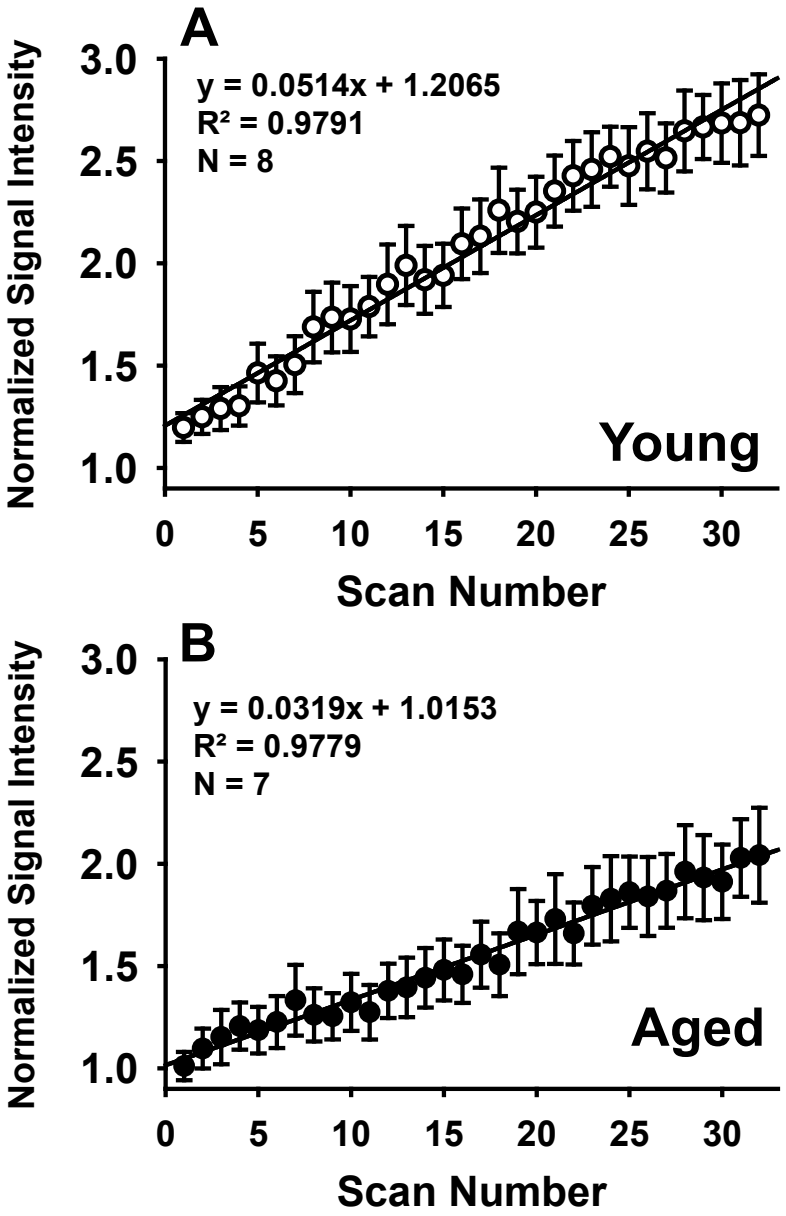
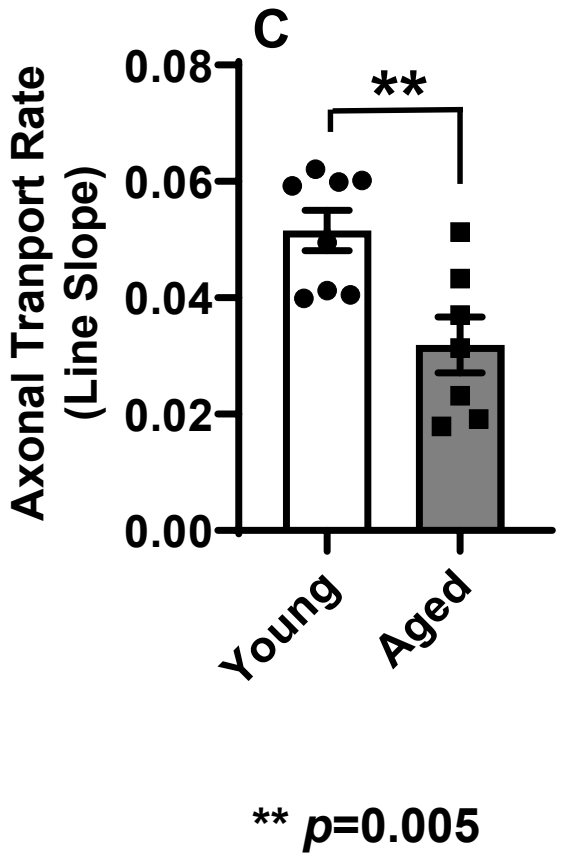


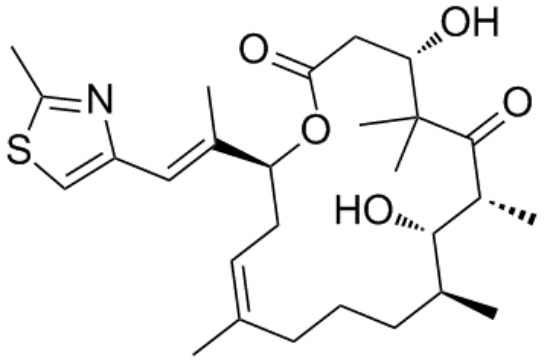
Fig 4

Axonal Transport Rate-Age Comparison (Mouse MEMRI)





** p=0.005



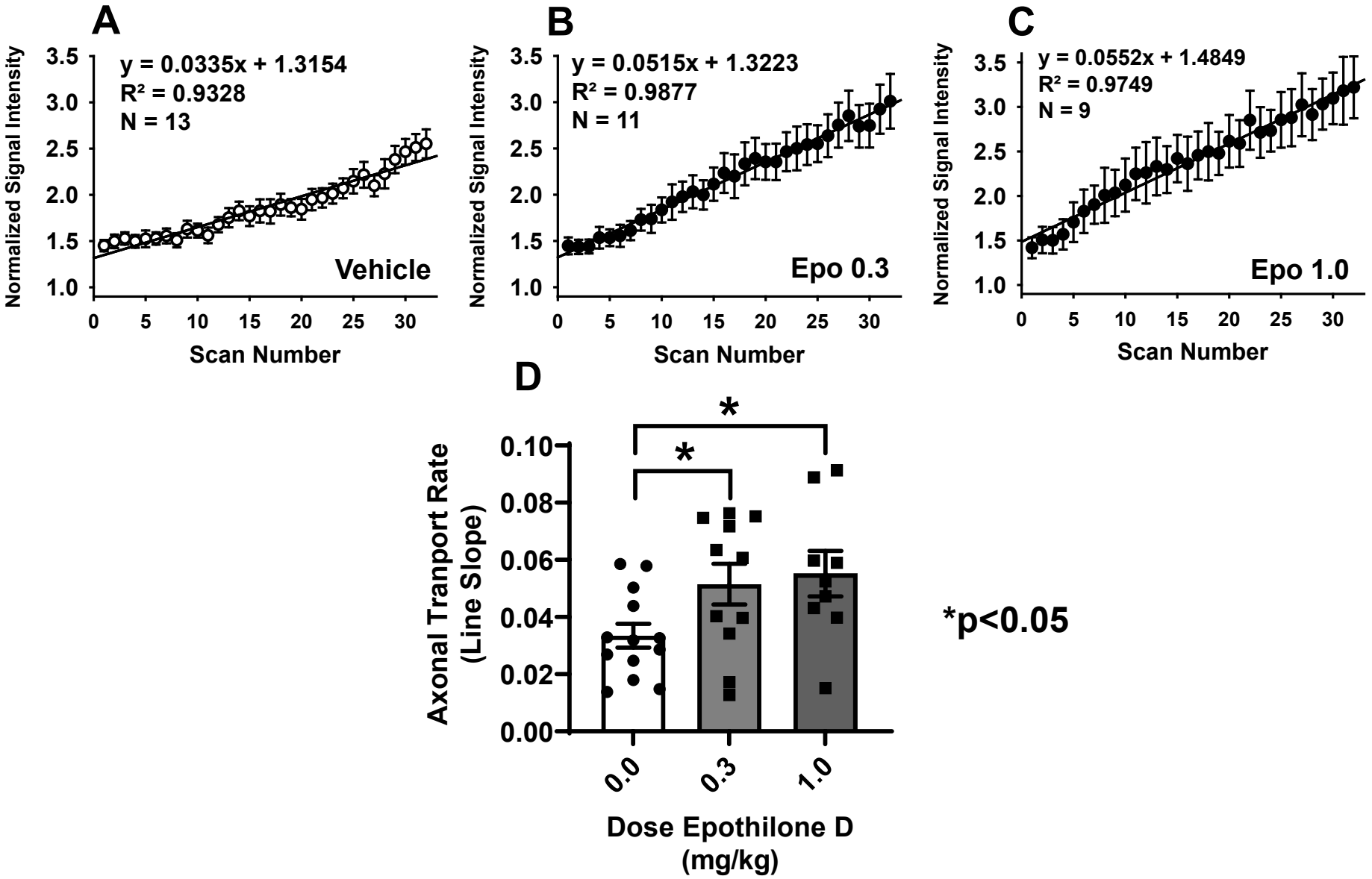
Epothilone D

Epothilone D is a brain-penetrant, microtubule stabilizing compound that has been shown in has been shown to improve axonal transport, other measures of neuronal function and cognitive deficits in Alzheimer's Disease and schizophrenia-related transgenic mice. Mechanism-epothilones bind to the αβ-tubulin heterodimer subunit and once bound, the rate of αβ-tubulin dissociation decreases, thus stabilizing the microtubules.
(Andrieux et al., 2006; Zhang et al., 2012; Daoust et al., 2014).

Mouse dosing protocol:

Epothilone D solution or vehicle was administered by intraperitoneal (i.p.) injection once per week for eight weeks prior to MEMRI analysis. Doses evaluated: 0.3 and 1.0 mg/kg.

Effects of Epothilone D on Axonal Transport (Aged Mouse MEMRI)



MEMRI: Effects of Epothilone D

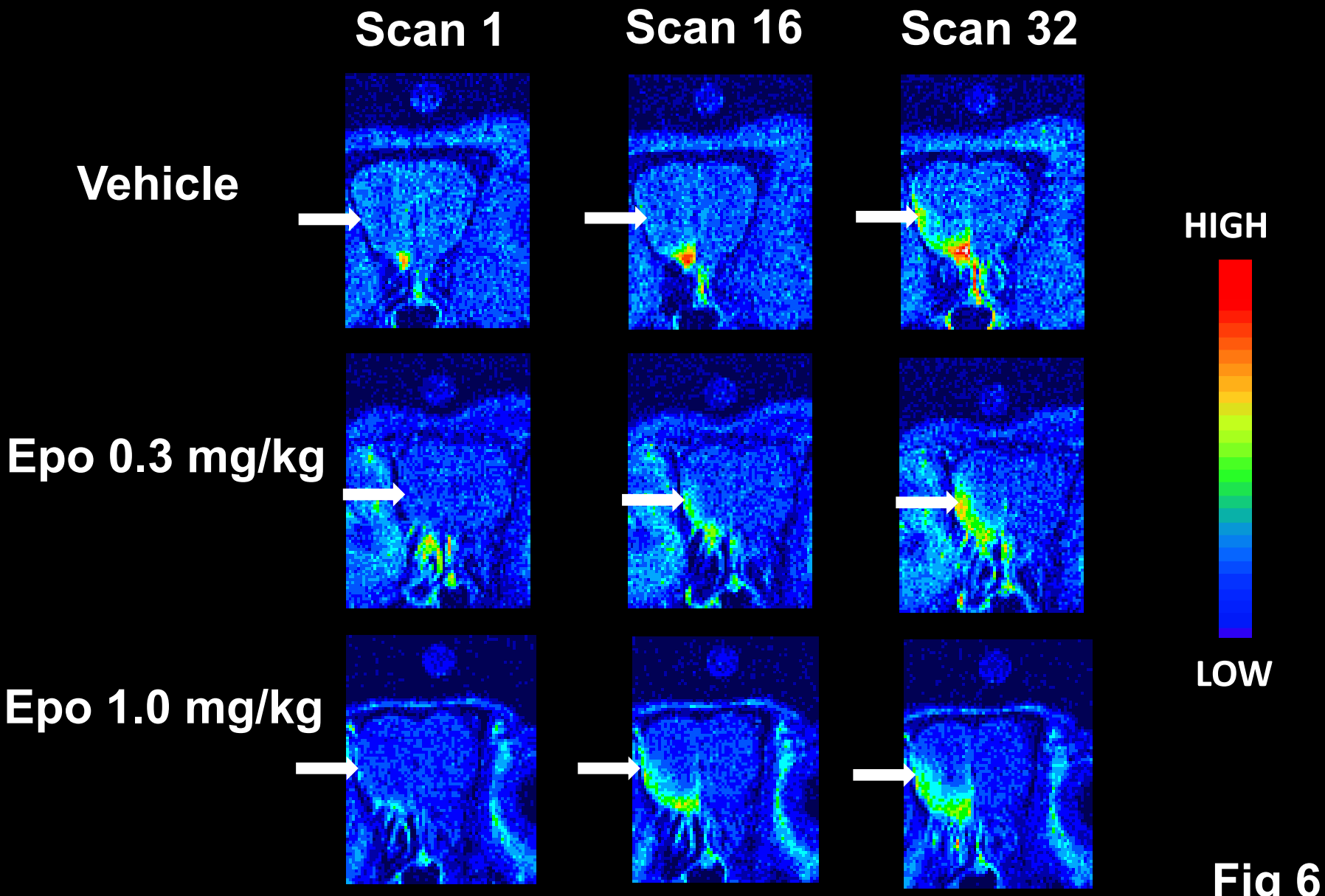


Fig 6

Summary/Conclusions I

- Our animal and neuronal culture experiments indicate that exposures to OPs of different classes (e.g., insecticide & nerve agent) can lead to impairments of axonal transport, a potential mechanism of the long-term neurological impairments observed in humans exposed to OPs.
- In vitro phenotypic screening studies indicate that some currently prescribed drugs (LiCl, MB) with multi-target pharmacological activity could have potential as repurposed drugs for OP-related neurological impairments as a result of their ability to attenuate the deleterious effects of OPs on axonal transport.

Summary II: New MEMRI Studies

- We have developed an improved MEMRI method where real-time measurements (32 time points) of axonal transport rates can be determined in vivo (mice) in the olfactory system over a single scanning session.
- Using this method we determined that axonal transport rates were clearly slower in aged vs young mice.
- In aged mice, the microtubule stabilizing compound Epothilone D was associated with statistically significant improvements in axonal transport rates.
- Conclusion- Our new MEMRI method is sensitive to the negative effects of aging on axonal transport as well as microtubule-focused therapeutic strategies for improving axonal transport. Future studies will focus on OP effects/therapeutic strategies using this method.

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  - Veterinarians
- **AU Office SVPR**
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  - Peter Baas, Ph.D.*
  - Anil Pillai, Ph.D.
  - David Hess, M.D.
  - Guangyu Wu, Ph.D.*
  - Dan Rudic, Ph.D.
  - Mark Hamrick, Ph.D.



















Simultaneous Inboard and Outboard, Inflight Measurements of Ultrafine Particle Concentrations

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International Aircraft Cabin Air Conference 2021
Online, 15 – 18 March 2021

Overview

- Motivation & the UK research aircraft
- The 3686 LP Ultrafine Condensation Particle Counter
- Data – total of 12 flights, 3 with aerosol composition
- Conclusion

Motivation

- Pre-pandemic, on average 4 billion passengers per annum.
- The indoor-outdoor interface at airports is unique – distinct from urban, for example.
- Exceptionally high concentrations of UFP from aircraft engines.
- Inflight events of UFPs have been reported.

Motivation

- Inflight events – suggestions are ingress of external air, cooking, passengers and contamination of bleed air (oil or decomposition products such as TCP).
- Previous studies speculate source of aerosol only.

BAe 146 research aircraft

A BAe 146 aircraft
4000 kg of science equipment and 18 people
Duration of 1-6 hours
Range: surface to 10 km
Reduce galley – Hot drinks only





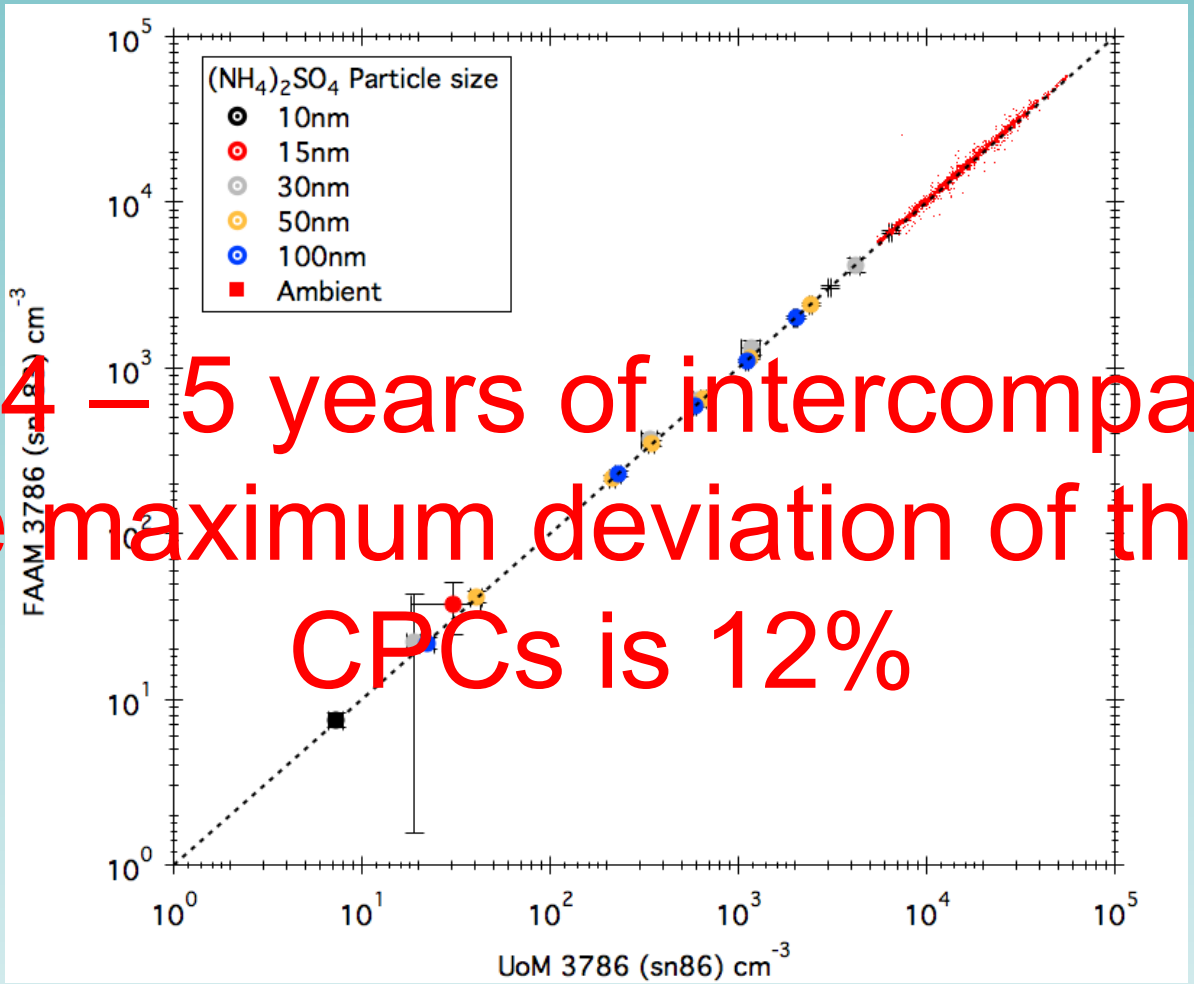


Quant/TSI 3786 LP UCPC



- Water based UCPC
- A modified version of a 3786 for low pressure applications
- D_{50} 2.5nm
- Range: Ambient to 180hPa
- Single count mode to 9.99e^{5} cm^{-3}
- Sadly obsolete

3786 LP performance

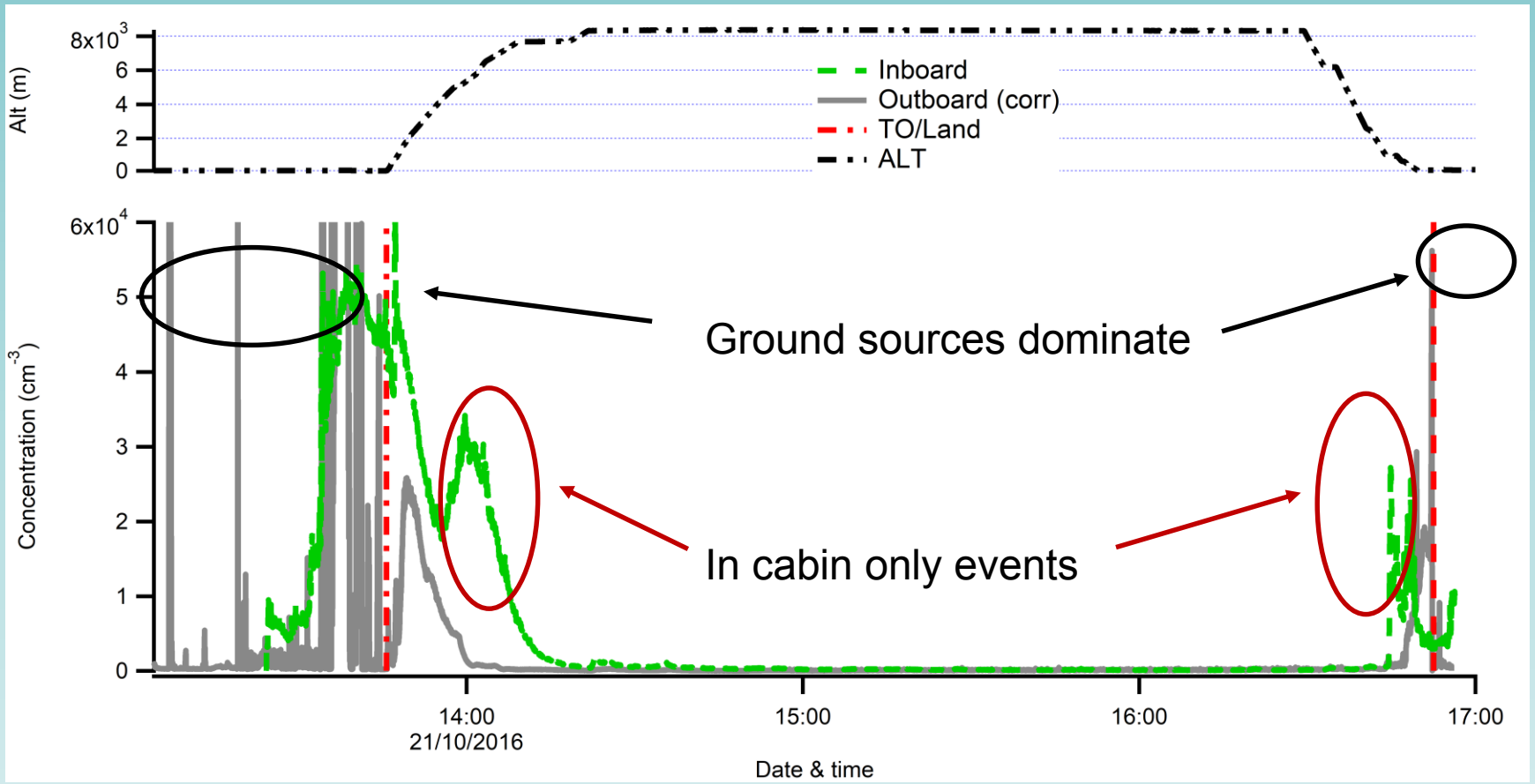


Over 4 – 5 years of intercomparison, the maximum deviation of the 2 CPCs is 12%

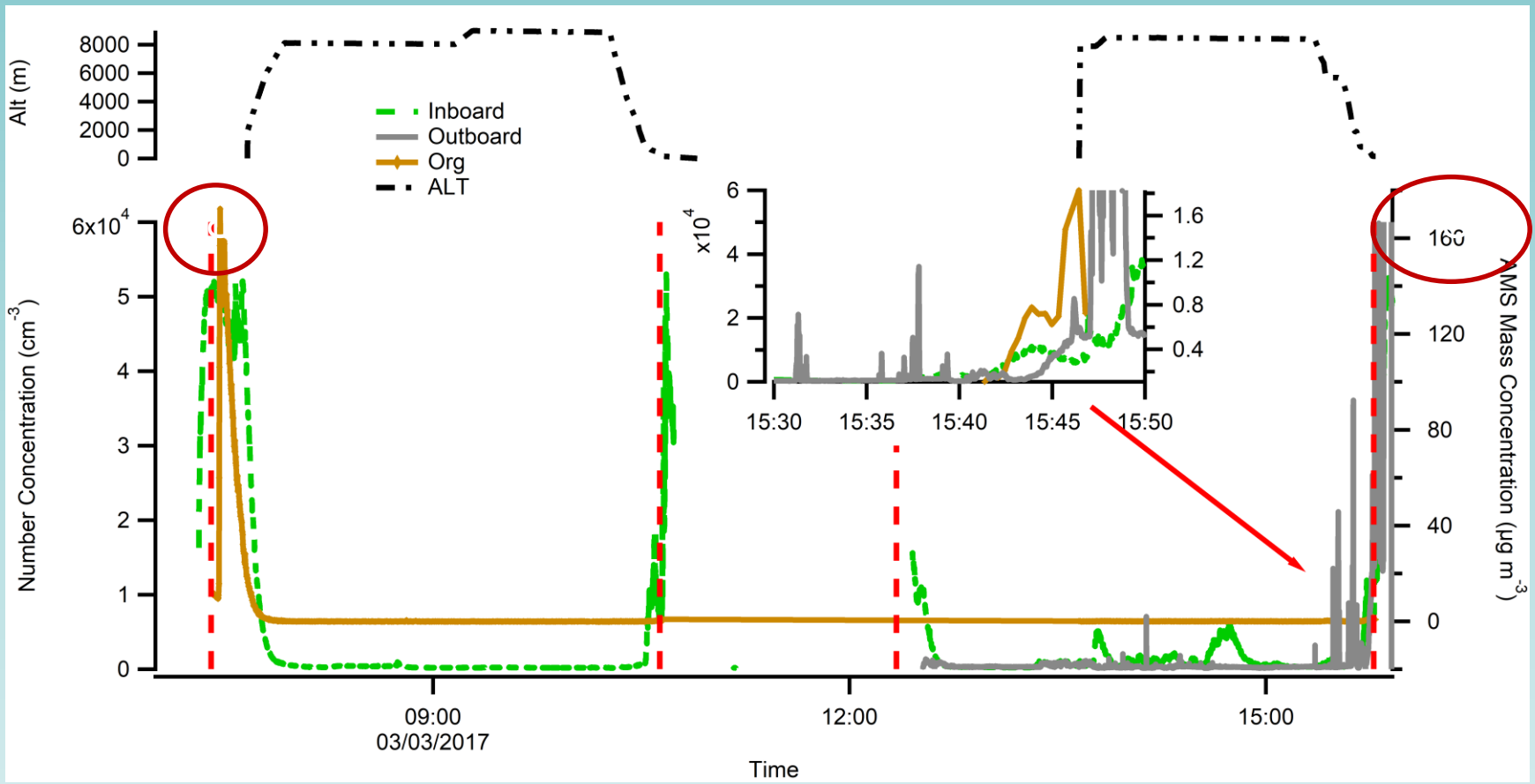
Data –opportunist sampling

- Volcanic and Atmospheric Near- to far-field Analysis of plumes Helping Interpretation and Modelling (VANAHEIM – based at Keflavik, Iceland)
- Methane Observations and Yearly Assessments (MOYA – Dakar, Senegal)
- Cloud and Aerosols Radiative Impact and Forcing (CLARIFY – Ascension Island).

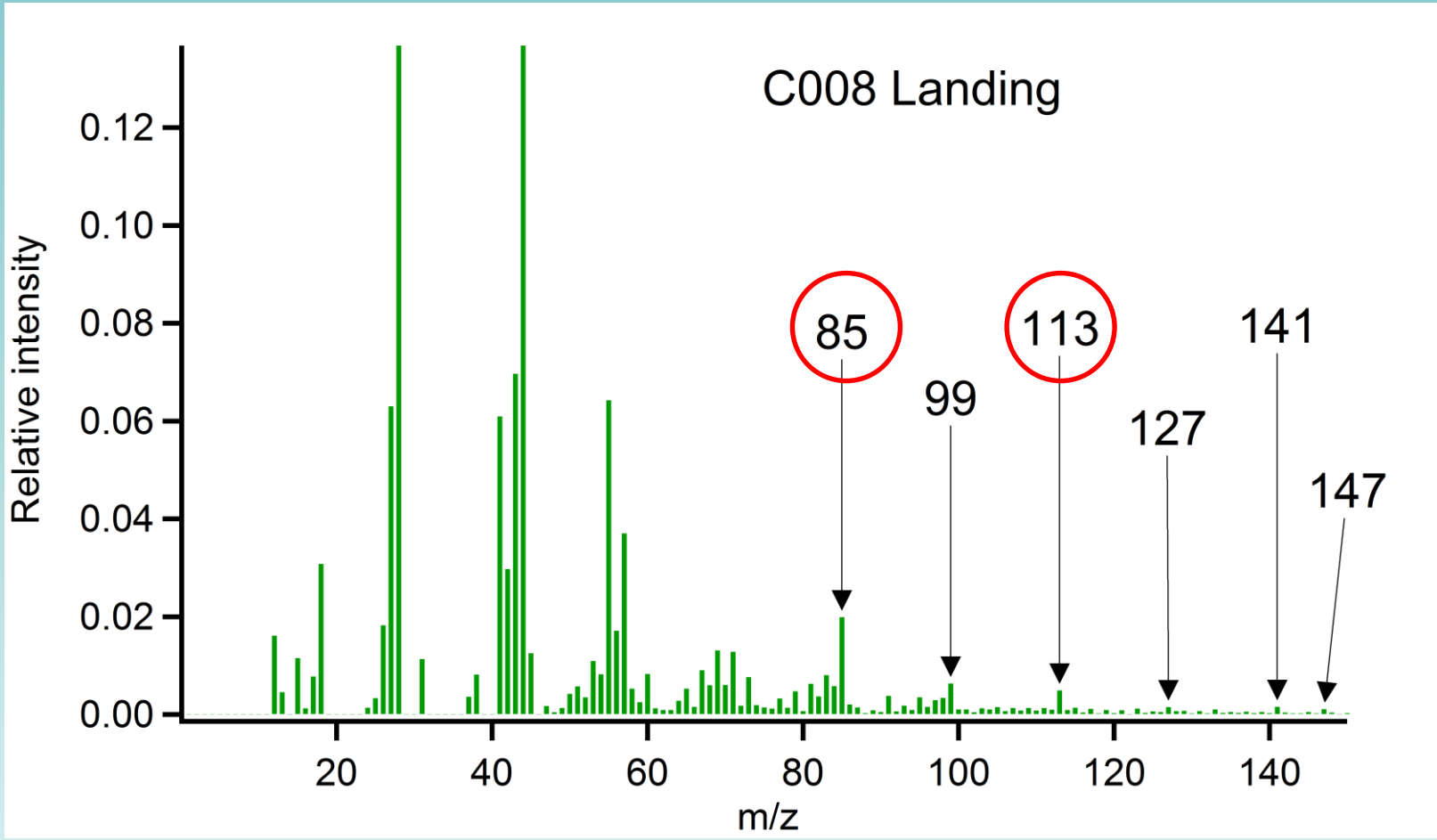
Results – P153 transit style



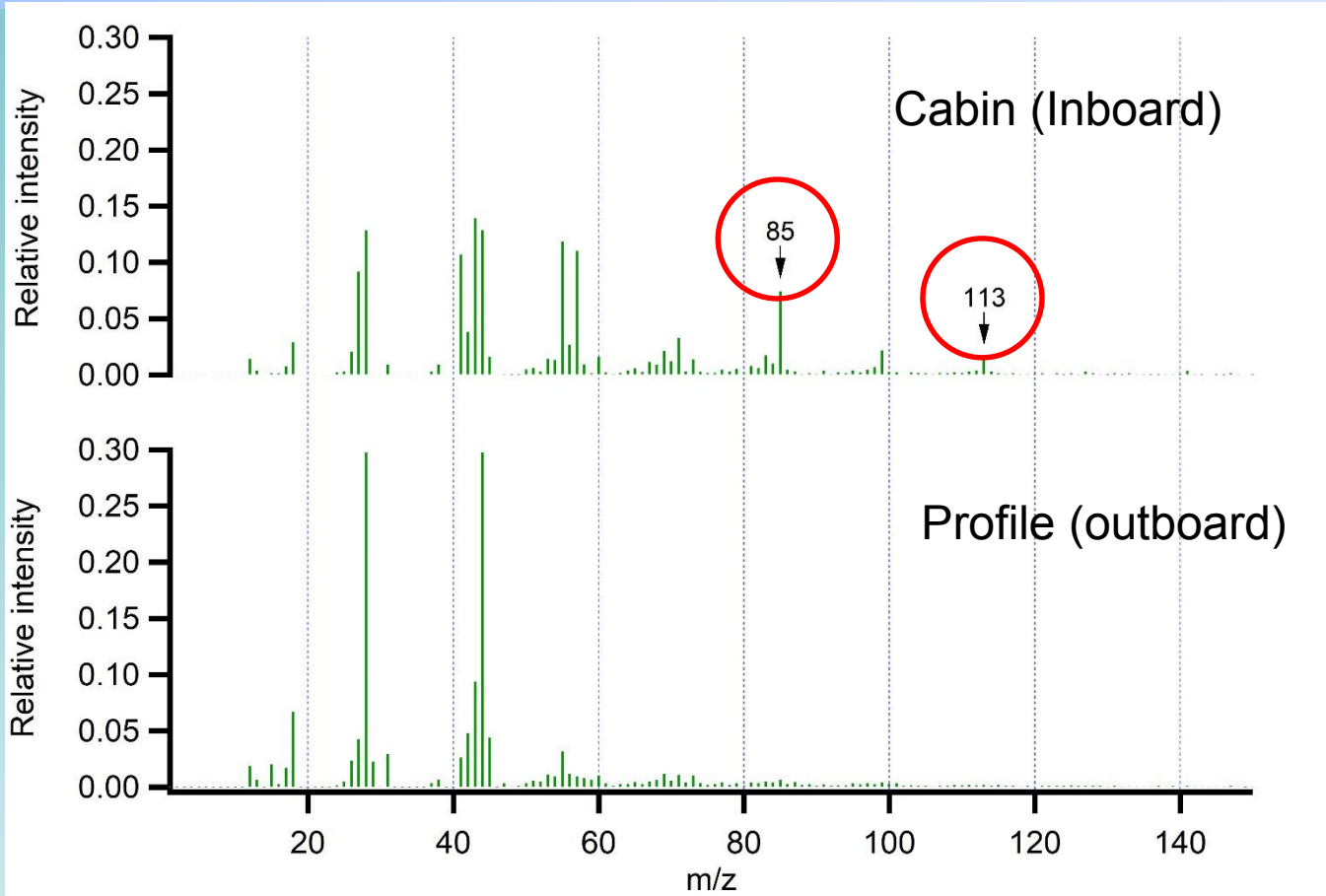
Plume event and in cabin



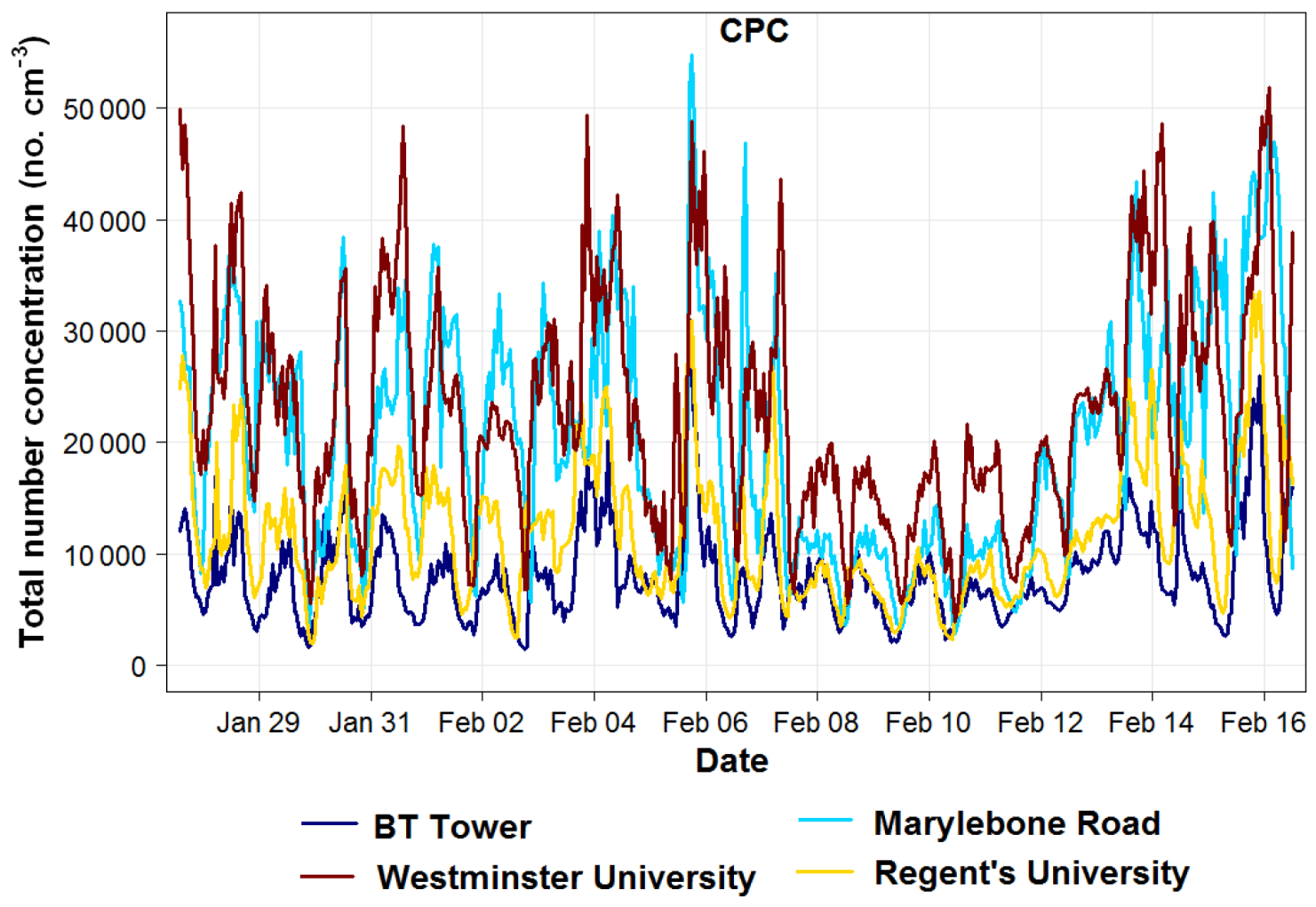
C008 landing – oil contribution?



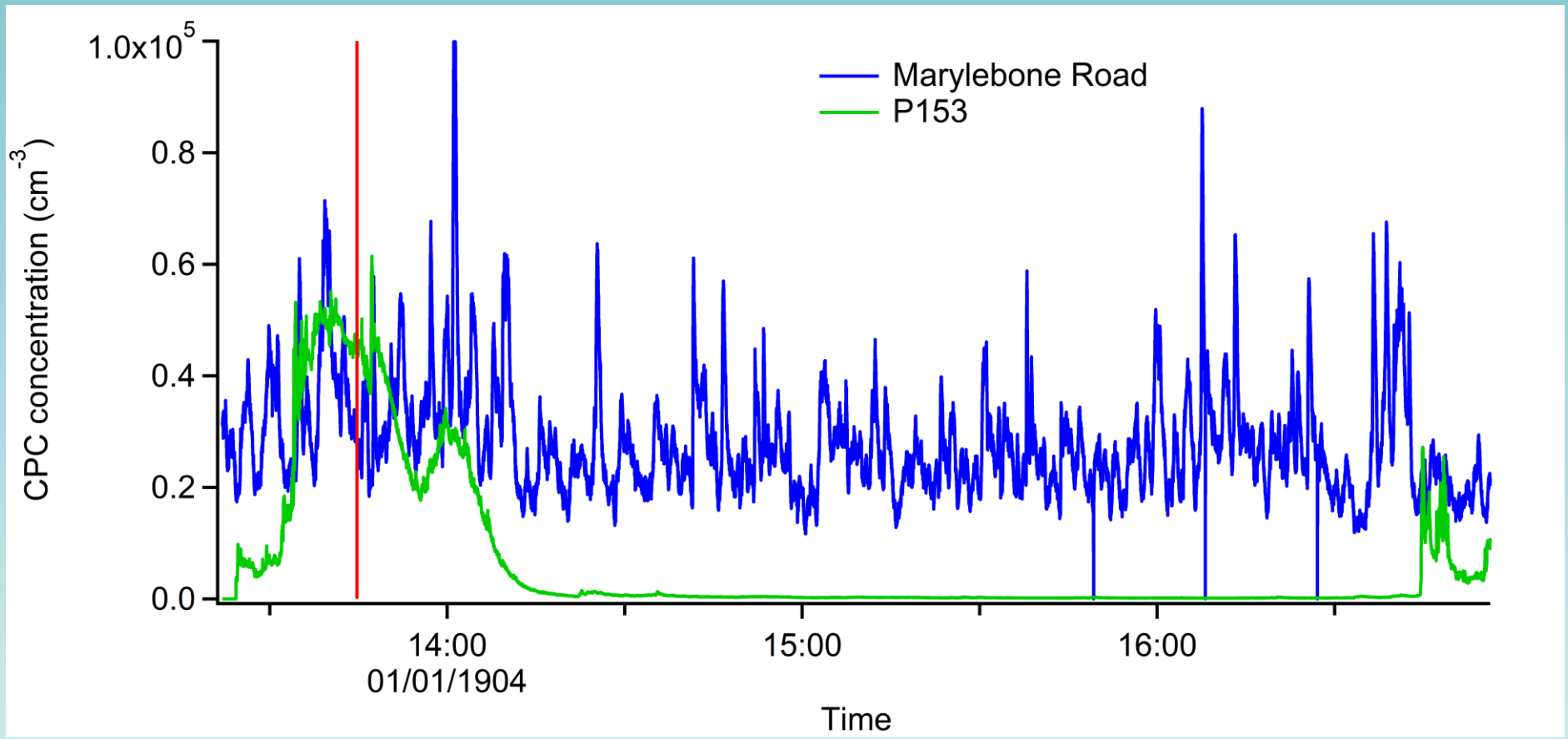
C040 Results – oil?



Context - number



Context - number



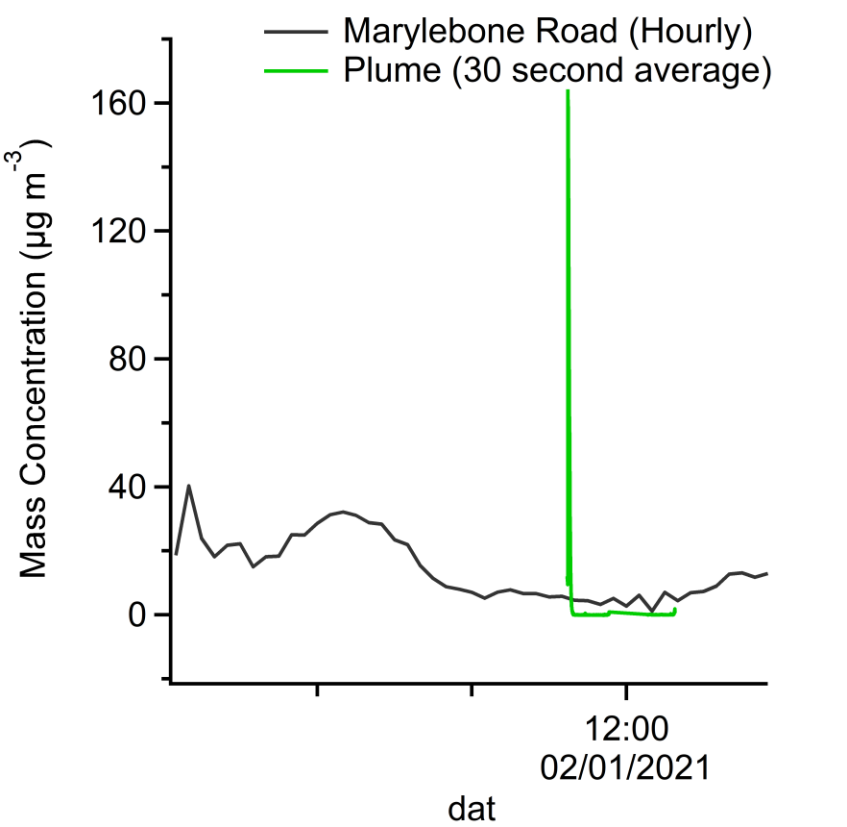
Context - mass

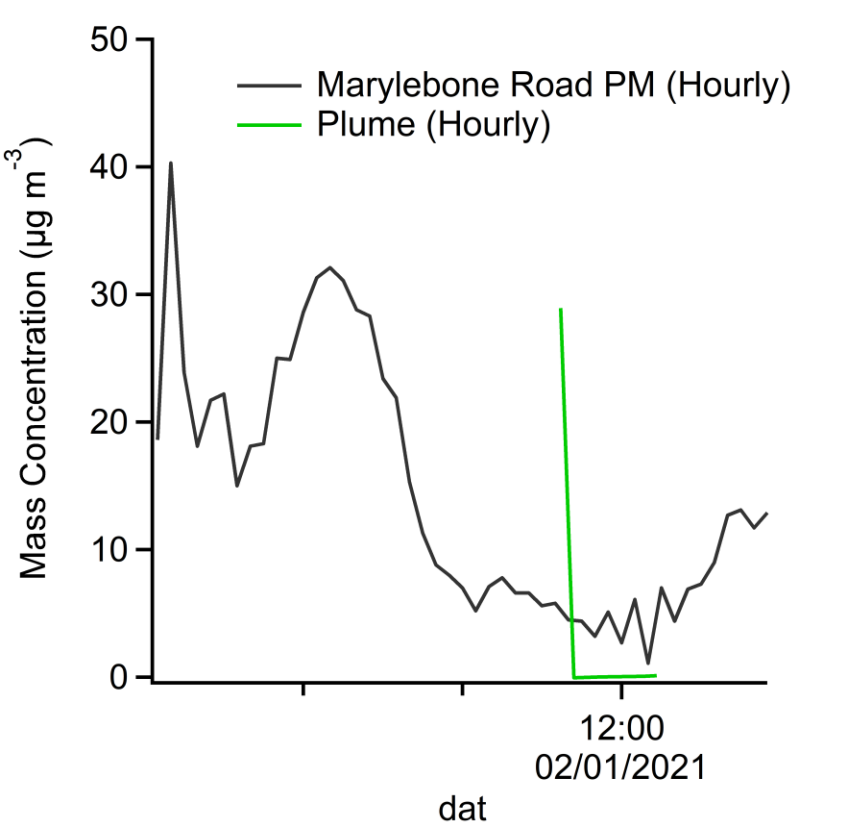




Smith et al., 2020, Env. Int., https://doi.org/10.1016/j.envint.2019.105188

Context - mass





Conclusions

- On the ground, before doors close, the number is dominated by ground sources.
- Number inside the cabin peak after doors close in 75% of flights.
- In flight, in cabin only UFP events occur in over 50% of cases on approach – change in aircraft engine.
- Chemical composition is a mixture of sources, but oil appears to be one component for the 146.
- There needs to be at least 3 parameters to have some confidence to identify the source of aerosol.

Conclusions

- Converting to average concentration, total exposure (ug m^{-3} hour) and average exposure per flight for mass all produce values below current workplace limits (comparing to 8 hour day) and ambient air quality limits.
- Calculated first estimate of number concentration total exposure and exposure per flight between 23,000 – 60,000 N cm^{-3} Hour and 6,800 – 10,800 N cm^{-3} per flight.
- Number concentration – equivalent to a London main road for events
- Mass concentration – Better than the underground; similar/worse* then main road (*delete as appropriate)
- published AS&T, 2021, https://doi.org/10.1080/02786826.2021.1880544

See you at the

2022 International
Aircraft Cabin Air Conference

14-15 September 2022, Online, Zoom



https://AircraftCabinAir.com